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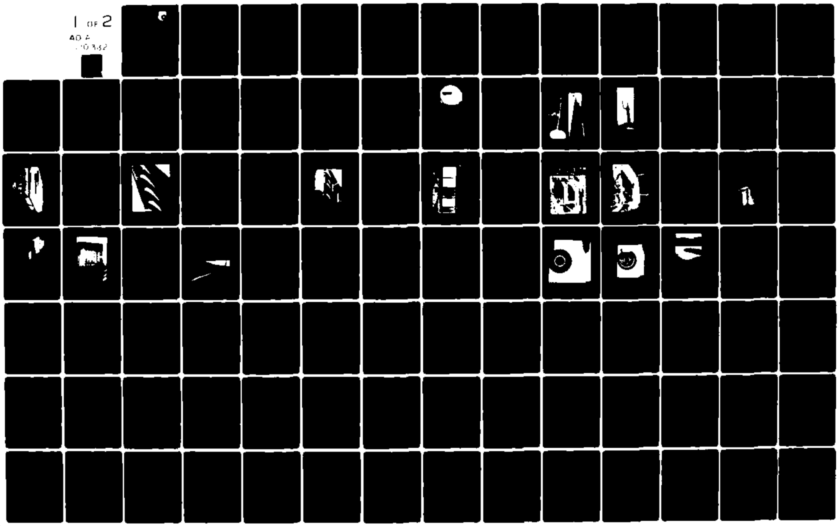

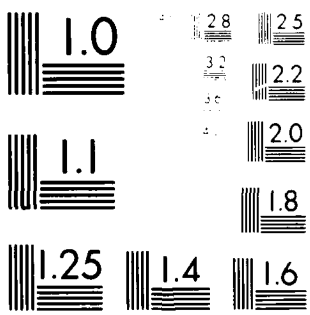

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EXPERIMENTAL INVESTIGATION OF TURBINE ENDWALL HEAT TRANSFER

Volume I. Description of Experimental Hardware and Test Conditions

L. D. Hylton, M. S. Mihelc, E. R. Turner, and R. E. York

Detroit Diesel Allison
Division of General Motors Corporation
P. O. Box 894
Indianapolis, Indiana 46206

August 1981

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DR KERVYN D. MACH
Project Engineer
Components Branch
Turbine Engine Division
Aero Propulsion Laboratory

CHARLES E. BENTZ
Manager, Hot Section Technology
Components Branch
Turbine Engine Division
Aero Propulsion Laboratory

FOR THE COMMANDER

ROBERT E. HENDERSON
Deputy for Technology
Turbine Engine Division
Aero Propulsion Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two turbine cascades were tested at simulated engine conditions to provide a data base of endwall heat transfer data. This data base is intended to be sufficiently complete to provide verification data for refined computational models developed to predict first-stage stator endwall heat transfer in advanced turbine engines.

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20. ABSTRACT (Cont)

A linear, two-dimensional cascade provided the bulk of the data. This cascade provided data to separate the effects of exit Mach number, exit Reynolds number, inlet boundary layer thickness, gas-to-wall temperature ratio, inlet pressure gradients, and inlet temperature gradients. In addition, adiabatic wall temperature and inlet turbulence intensity data are available for the linear cascade runs. A computerized data base was generated. This data base, with its associated software management system, provides the user with relatively easy access to the vast amount of data generated.

A full annular, three-dimensional cascade was used to acquire data for identifying the radial pressure gradient effects. Tests in the annular cascade were run over a wide range of exit Mach and Reynolds numbers and gas-to-wall temperature ratios, all at levels typical of advanced engines.

SUMMARY

The purpose of this experimental investigation was to produce a data base of endwall heat transfer data that was acquired under conditions that simulate those in the passage of the first-stage stator in advanced turbine engines. The data base is intended to be sufficiently complete to provide verification data for refined computational models, and to provide a basis for advanced core engine endwall cooling designs.

The testing was conducted in two cascades. The first was a linear, two-dimensional cascade that was used to generate the bulk of the data base. The test plan for this cascade was organized to span the principal factors expected to influence vane endwall heat transfer and associated aerodynamics, except for radial pressure gradient effects. A full annular, three-dimensional cascade was used to acquire data for identifying the radial pressure gradient effects. Tests in the annular cascade were run over a wide range of exit Mach and Reynolds numbers and gas-to-wall temperature ratios, all at levels typical of advanced engines.

The test plan for the linear cascade provided data to separate the effects of exit Mach number, exit Reynolds number, inlet boundary layer thickness, gas-to-wall temperature ratio, inlet pressure gradients, and inlet temperature gradients. In addition, adiabatic wall temperature and inlet turbulence intensity data are available for the linear cascade runs.

The vast amount of data generated in the linear cascade tests made it necessary to generate a computerized data base. This data base, with its associated software management system, provides the user with easy access to the data for a variety of purposes such as extensive comparison with analytical prediction, cross correlation and plotting, and (eventually) use in a turbine design system.

The results of this program are presented in three volumes. Volume I documents the facilities, cascade geometry, instrumentation, and data acquisition techniques. Particular emphasis is placed on describing the type and locations of all measurements made in the program. Volume I also contains a summary of test conditions and a sample summary data set for both cascades. Volume II contains the summary data sets for each of the linear and annular cascade runs. Volume III describes the computerized data base and contains a Users Manual for the associated software.

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VOLUME I

1.0 INTRODUCTION

The development of fundamentally sound procedures for the design of endwall heat transfer systems in advanced, high-pressure, high-temperature, low-aspect-ratio turbines is essential to meeting the performance and durability requirements of many advanced propulsion systems. The advantages of high pressure and high temperature to the gas turbine thermodynamic cycle are well known and documented. Nevertheless, the temperature levels in actual production engines are well below the stoichiometric temperatures that could be produced in the combustion system and are observed to be increasing rather slowly with time. This slow but systematic increase in turbine operating temperatures can be attributed largely to the slow development of effective cooling systems for those parts in the high-temperature gas stream.

Elaborate cooling systems have been developed for turbine airfoils, based primarily on two-dimensional design hypotheses. Through careful iteration between design analyses and development testing, these cooling systems have made it possible to make use of the thermodynamic advantages of high temperature without excessive compensating losses in terms of efficiency penalties for the cooling air, or reductions in service life due to lack of durability. As operating temperatures are increased, it becomes increasingly important to provide cooling for the turbine endwalls, as well as for the airfoils.

The endwall heat transfer design problem is important not only to provide durability of the endwall itself, but also because the endwall temperature field can produce thermal distortions which promote serious stresses in the airfoils as well. Yet, no adequate design analysis is currently available. This lack of design capability is the result primarily of the complexity of the flow field in the endwall region. This flow field, which must be modeled with precision if the local heat transfer is to be accurately represented, is strongly three-dimensional and viscous in nature. Thus, direct extensions of the approaches used for airfoil heat transfer design are not at all adequate for the endwall problem. Based on Detroit Diesel Allison (DDA) experience in similar problem areas, the solution of this problem will require an analytical model that adequately represents all the secondary flow and viscous shear elements in turbine nozzles that are important to the local heat transfer process, but that is not so complex as to be prohibitive in terms of computational cost. Further, to ensure the proper phenomenological content in such a model, it is imperative that accurate, independent, and representative experimental data be made available for evaluation purposes. Finally, the design procedure that results from this combined analytical and experimental effort must be evaluated by means of major component rig or engine testing.

The specific purpose of the program reported herein is the acquisition of representative, independent, and accurate experimental data to provide the basis for the development of a high-quality, endwall heat transfer design system.

2.0 TECHNICAL APPROACH

The technical approach utilized in this program provides a thorough experimental investigation of endwall heat transfer by a unique technique that makes the results directly applicable to the gas turbine engine operating environment. This can be accomplished in such a fashion that discrete instrumentation can be included to provide detailed aerodynamic and heat transfer data describing the controlling phenomena, so that a data base is formed that can be used to verify refined computational models, and on which advanced core engine endwall cooling designs can be based.

The essence of the problem from the designer's point of view is that the currently available methods for predicting the heat loads over the vane endwalls are not capable of providing accurate information about the local distribution of heat transfer.

To improve this situation, the designer needs a substantial improvement in predictive capability. He needs to be able to predict, in detail, the three-dimensional, viscous endwall flow structure and the associated thermal transport. He needs to be able to include the interacting effect of the strong passage secondary flows that characterize modern, highly-loaded, low-aspect-ratio, core turbines. The effects of the gas turbine environment--strong accelerations, transonic flow velocities, high turbulence levels, high heat flux levels, etc--must be accurately accounted for.

Advanced, three-dimensional, viscous, compressible fluid flow calculations to meet these needs are being developed at most companies within the gas turbine industry and at many universities. These calculations, together with continually decreasing cost of computation, will be the core of design technology within a few years. As always in the past, an understanding of the controlling phenomena must be built into the internal models of such computations in order to provide them with the necessary accuracy to be sufficiently reliable for design.

Once developed, analytical models cannot be readily employed until they have been thoroughly verified by comparison with representative data. The data base needs to be accurate, detailed, and broad, so that all aspects of the problem that the designer will encounter can be checked separately. It must also be generated by an experimental study that is as representative of the engine as can be contrived, while still meeting the needs for detailed, quantitatively accurate descriptions of the separate but interacting aerothermodynamic phenomena.

In establishing a broad-base experimental program, such as the one reported here, it is extremely important to evaluate carefully the critical factors that will become independent parameters. Ultimately, the list of critical factors must be made as small as possible without eliminating any element in the program that is essential to the critical analysis of the endwall heat transfer design system. The following paragraphs provide the basis for the selection of these critical factors.

The factors that must be important to endwall heat transfer can be identified in terms of two distinctly different groups. The first, or design, group identifies the discrete engine hardware geometry and operating conditions, and is necessary to evaluate a specific design. The second, and more useful, phenomena group considers the specific physical elements of importance. The design grouping would recognize the following critical factors: all elements of airfoil geometry, such as turning, chord, span, spacing, leading edge radius, hub-tip radius ratio, and camber distribution. The engine operating conditions would also impact heat transfer markedly. These factors could be described by inlet temperature and pressure levels, inlet total temperature, total pressure and Mach number gradients, and vane expansion ratio or exit Mach number. Additional factors that would impact the vane inlet conditions are the burner geometric shape, dilution air injection geometry, burner-to-vane transition area ratio, and transition cooling. The addition of film cooling would require additional factors for the cooling air injection geometries, such as hole spacing, size, and angle, the coolant temperature, and the amount of cooling air.

The group of design factors does not recognize any of the phenomenological information that is known about the endwall flow system and vane secondary flow patterns in general. A significantly reduced list of critical factors can be established for this experimental program by making use of existing pertinent knowledge as long as similitude is retained between test and engine operating conditions. It is through the use of this knowledge that the phenomena group becomes advantageous in planning the experimental program.

It is widely accepted that similitude between experimental and engine operating conditions must be maintained until experimental results are obtained to justify the relaxation of any of the similarity constraints. Adequate data are not available today to relax similarity constraints for the three-dimensional, endwall heat transfer problem. The equations of motion and their boundary conditions reveal that exact similitude between the flow within the cascade and the engine flow is achieved, provided that the following dimensionless parameters have the same values in both situations.

- The dimensionless airfoil geometry
- The mainstream inlet Mach numbers
- All coolant flow inlet Mach numbers
- All coolant-to-gas weight flow ratios
- The gas Reynolds number
- All coolant flow Reynolds numbers
- The gas Prandtl number
- All coolant flow Prandtl numbers
- The distribution of the ratio of wall surface temperatures to inlet gas total temperature
- The distribution of the ratio of wall surface temperatures to coolant total temperatures
- The gas and coolant inlet turbulence distribution levels

The application of these similarity constraints allows the absolute pressure and temperature levels to be reduced below their engine values. However, these parameters, plus the model scale, must be chosen so as to preserve gas Reynolds number and the wall/gas/coolant temperature ratios. These important

freedoms have been used to greatly increase the effectiveness of this program. To increase the effectiveness further, the specific controlling flow phenomena have been identified as the controlling factors, rather than the discrete geometric and operating parameters considered in the design group. This phenomena group of controlling factors for the endwall case includes the following:

- o Streamwise pressure gradients
- o Cross-channel pressure gradients
- o Spanwise pressure gradients
- o Inlet momentum boundary layer thickness
- o Inlet thermal boundary layer thickness
- o Inlet turbulence distribution
- o Wall-to-gas temperature ratio
- o Gas Reynolds number

The primary importance of this list is that it is shorter than the design group list, yet still contains all the parameters required for a critical evaluation of the endwall heat transfer design system. The reduction in number results from the fact that several design factors produce equivalent changes in the same phenomena.

These factors, then, form the basis for the experimental program that produced this data base. Several alternate experimental approaches to meeting these requirements were considered. The DDA aerothermodynamic cascade facility (ACF)--a linear, steady-state cascade facility--was selected to conduct the major part of the program. In order to acquire data on the effect of radial pressure gradient, a full annular test was conducted in the DDA small turbine research facility.

The aerothermodynamic cascade facility (ACF) is uniquely suited for the performance of the experimental program required to build a data base of endwall heat transfer in a direct simulation of the gas turbine engine. The ACF was designed specifically to meet the similitude requirements enumerated above. The ACF is not simply a hot wind tunnel but has been designed from the beginning as a means of examining the interacting effects of aerodynamics and heat transfer in a single test, thereby ensuring the correlation of data. This facility, coupled with unique experimental techniques and capabilities available at DDA, provide the means of acquiring the required data for the endwall heat transfer data base.

In summary, the technical approach is to provide an accurate, independent, and representative experimental data base by making measurements in steady-state cascade facilities that fully simulate engine conditions. The details of the facilities, the cascades, the instrumentation, the experimental techniques, and the test plans are given in Sections 3 and 4 of Volume I.

3.0 EXPERIMENTAL HARDWARE AND INSTRUMENTATION TECHNIQUES

This section provides a detailed description of the techniques used to make the measurements in both the linear and annular cascades. Also detailed are the types and precise location of all instrumentation. Facility descriptions are included, as is cascade geometry. This section is intended to provide the reader with all the information necessary to apply the data to verifying a computational code.

3.1 HEAT TRANSFER MEASUREMENT TECHNIQUE

One of the best methods for heat flux evaluation to be developed is the use of the test piece itself as the fluxmeter. Turner (Reference 1*) employed this method for the study of turbulence level effects on vane heat transfer. It has been used extensively at DDA (Reference 2-7). Basically, it is implemented by installing thermocouples on the interior and exterior surfaces of the test piece, which is then placed in the test environment and run until thermal equilibrium is obtained. The temperature data then become the boundary conditions for a finite element solution of the internal temperature field of the test piece. The surface normal temperature gradient is derived from this solution, and the local heat transfer coefficient distribution can be directly evaluated. A schematic illustrating application of the technique to measuring vane external heat transfer coefficients is shown in Figure 1.

The uncertainty associated with the data acquired by this technique has been demonstrated in previous tests (Reference 7) to be primarily dependent on the accuracy with which the surface temperatures can be measured, in comparison with the temperature difference through the structure. The cumulative errors attributable to reference junction drift, thermocouple wire calibration, voltage measurement, and calibration table interpolation amount to less than 1.0°F. Uncertainties in the corrections to account for installation in cement-filled grooves and variations in the details of physical installation are more significant (about 2°F). Turner (Reference 8) presents an analysis of the error induced by the presence of the thermocouple and groove. It is important in the design of a grooved thermocouple installation to be conscious of the potential thermometry errors, and to structure the design to minimize the size of temperature correction that must be made. Careful design can result in a nearly negligible correction. By material selection and strong cooling, a large ΔT can be established so that the relative uncertainty in ΔT and, ultimately, heat flux, can be made acceptably small. Additional errors in translating ΔT data to heat flux values can be minimized. Thermal conductivities are well established if materials are bought by specification. The finite element accuracy can be verified by successive grid refinement and comparison with exact solutions. The method inherently includes conduction corrections. The method also measures the total heat flux due to both convection and radiation. The radiation contribution is kept small by keeping the cascade wall temperatures near that of the vanes so that little potential for radiation exchange would exist. The cumulative uncertainty in heat flux values due to all these factors is estimated at 10-15 percent.

*All references are listed in the Reference Section located at the end of this report.

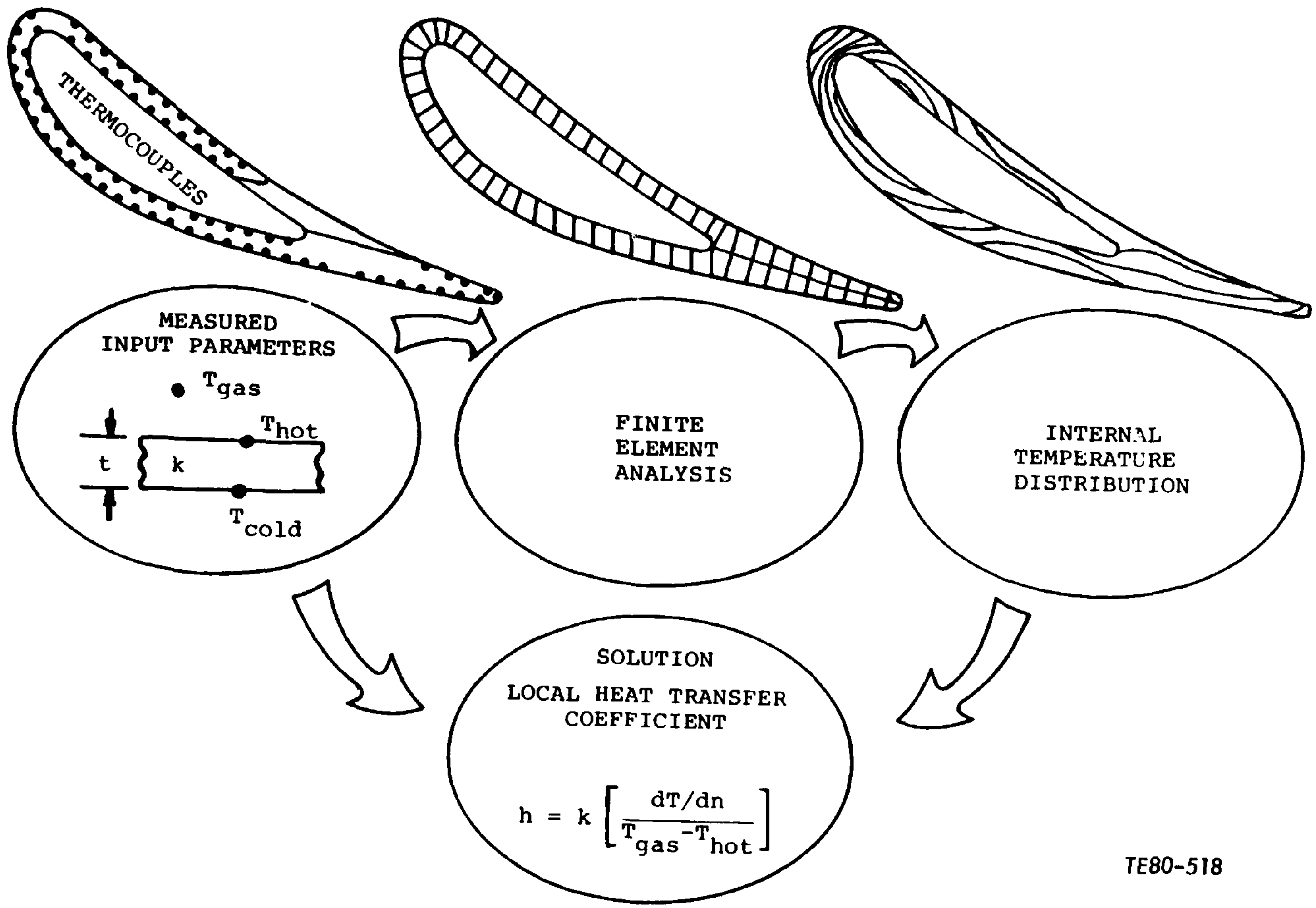

Figure 1. Finite element heat transfer measurement technique.

This method has many advantages. First is cost, since this method requires only thermocouple instrumentation. Second, the method provides good spatial resolution, being limited only by a grid size selected for thermocouple locations. Third, it permits testing to be conducted with the correct heat flux sense--i.e., hot gas with cold wall--and with similitude to an engine temperature ratio of T_w/T_g. The developed ability to measure the local heat transfer coefficient in conjunction with this parameter's sensitivity becomes a powerful experimental tool which is used in addition to standard aerodynamic cascade instrumentation.

3.2 LINEAR CASCADE

3.2.1 Facility Description

The linear cascade portion of the contract was performed in the DDA Aerothermodynamic Cascade Facility (ACF). The purpose of this facility is to conduct experimental research in high-temperature turbine component models that embody advanced cooling techniques, aerodynamics or materials. The experimental approach employs a two-dimensional model technique, with full dynamic similarity in free-stream Mach number and boundary layer Reynolds number effects, and provides an experimental method to separate the effects on local heat transfer.

Operationally, the facility consists of a burner, a convergent section, a free-stream section with instrumentation, a test section with instrumentation, a quench zone with back pressure regulation, and the exhaust system. The facility is shown schematically in Figure 2.

The Mach and Reynolds number modeling considerations necessitated a burner with a large temperature, flow, and pressure range. This burner capability, coupled with the back pressure regulating valve, allows experimental separation of free-stream (Mach number) and boundary layer (Reynolds number) effects to accurately simulate a wide range of engine designs and operating conditions.

A constant cross section is provided downstream of the burner to establish uniform inlet velocity, temperature, and turbulence profiles. This section is provided with temperature-controlled cooled walls and isolates the test section from radiant heat transfer from the primary combustion zone.

The test section design is unique in that it incorporates both aerodynamic and heat transfer data acquisition in a single tunnel, thereby reducing costs and ensuring the correlation of heat transfer and aerodynamic data for the single set of airfoils.

The test section consists of an array of five test vanes. The vanes can be scaled to attain low cost but still permit complete instrumentation on the vanes and endwalls in the gas path areas. The use of scaling, while maintaining both Reynolds and Mach number similarity, allows a low-cost-per-data-point return and maximum flexibility in experimental design.

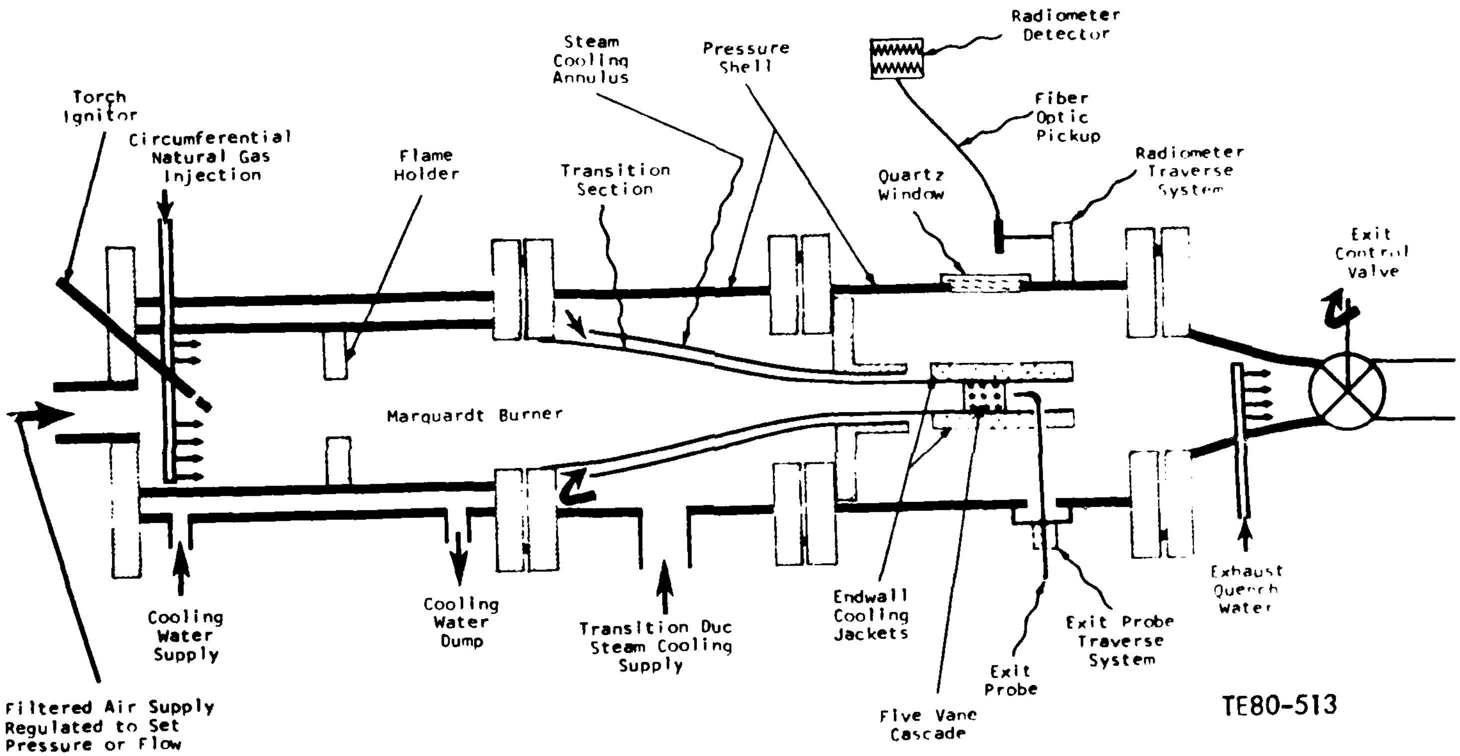

Figure 2. Schematic of aerothermodynamic cascade facility.

The walls of the test section are cooled with steam to keep them at, or close to, the vane surface temperature to prevent radiant exchange. The total span of the test section is 3.0 inches which permits the acquisition of aerodynamic data in the gas path, as well as the acquisition of vane and endwall data.

The various flow circuits of the aerothermodynamic cascade facility incorporate standard in-line instrumentation for measurement of flow rate, pressure, and temperature. ASME standard sharp-edged orifices are used throughout to provide flow rate measurements accurate to ±2%. Facility and rig pressures are measured using a Scanivalve pressure scanner having six modules, each capable of 48 individual sense lines. Pressure transducers of appropriate ranges, matched to the current experiment, are inserted in these modules. These pressure transducers are calibrated before each test series with a precision Mensor quartz manometer which, in turn, is periodically calibrated against a dead-weight system. Temperature measurements are customarily read through the 300 CA thermocouple circuits available in the laboratory, coupled to the data acquisition system through temperature-stabilized reference junctions. Patch panels for other sensor and control signals already connect the laboratory and the adjoining control room.

The facility test section is equipped with a computer-controlled, three-axis traversing capability to evaluate the complete exit plane field. A two-axis computer-controlled traverse system provides inlet pressure and temperature fields, including boundary layer regions. Provisions also exist at the cascade inlet plane for optical access to the flow path. Specifically, quartz windows can be installed in the cascade outer wall to permit the measurements of free-stream velocity and turbulence with a laser doppler anemometer (LDA) system. The LDA optical system can be mounted on a three-axis milling machine base to provide complete survey capabilities. Specifications regarding facility instrumentation are detailed in Table 1.

TABLE 1. AEROTHERMODYNAMIC FACILITY INSTRUMENTATION

Pressure scanner	Scanivalve system with 288 ports
Pressure transducers	Druck, with ranges from 0-10 psia to 0-500 psia
Accuracy	± 0.06% BSL
Thermocouple channels	300 Cr-Al + 40 Pt/Pt-10% Rh
Accuracy	± 0.5°F w/calibration
Traversing gear	United Sensor traversing probe mounts with computer interfaces. Precision 2-axis digital traversing mount with discrete stepping capability to 0.001 in.
Anemometers	Single- and dual-sensor hot-wire, hot-film anemometry Laser doppler anemometer (LDA)
Survey probes	Traversing Cr-Al thermocouple Traversing five-port cone and prism probes

The control room of the aerothermodynamic facility contains a dedicated computer-controlled data acquisition system, shown in Figure 3. A/D conversion is accomplished through a 200-channel Hewlett-Packard (HP) 2302 subsystem. The computer main frame is an HP 2112B with 32K words of memory. Input/output devices complementing this CPU consist of an HP 7900A magnetic disk drive (1.2 M words), line printer, CRT terminal, tape reader, tape punch, and pen plotter. A multitask, facility-oriented software system containing general subprograms exists to do all the routine control and measurement tasks. The system is exceptionally flexible and provides for real-time facility monitoring and the diagnosis of instrumentation or control problems. The system also serves as an additional computational resource for general problem solving whenever an experiment requiring real-time system utilization is not being conducted.

3.2.2 Facility Geometry and Instrumentation

The flow path upstream of the cascade in the ACF takes the burner discharge from a 12.4-inch diameter through a 20-inch long transition section to a 3-inch x 11-inch rectangular section. This 11-inch long rectangular section is the inlet to the cascade. A photo of the transition duct and rectangular section is shown in Figure 4.

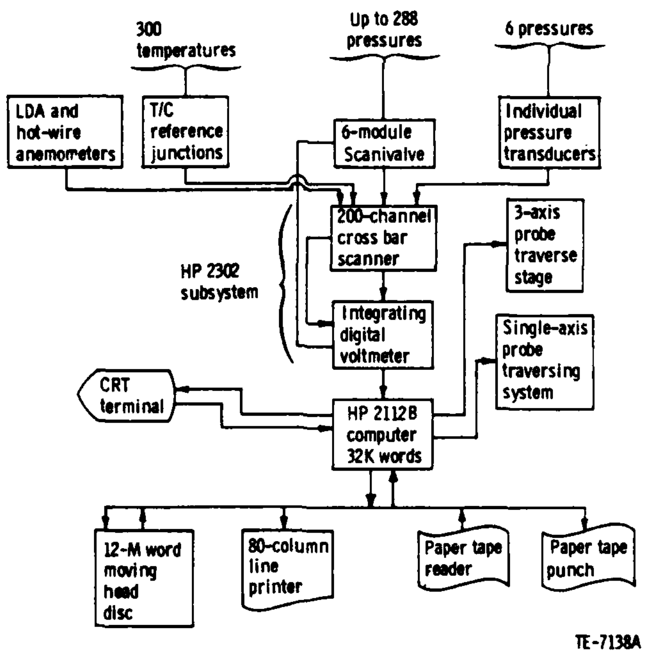

Figure 3. Aerothermodynamic cascade facility data acquisition system schematic.

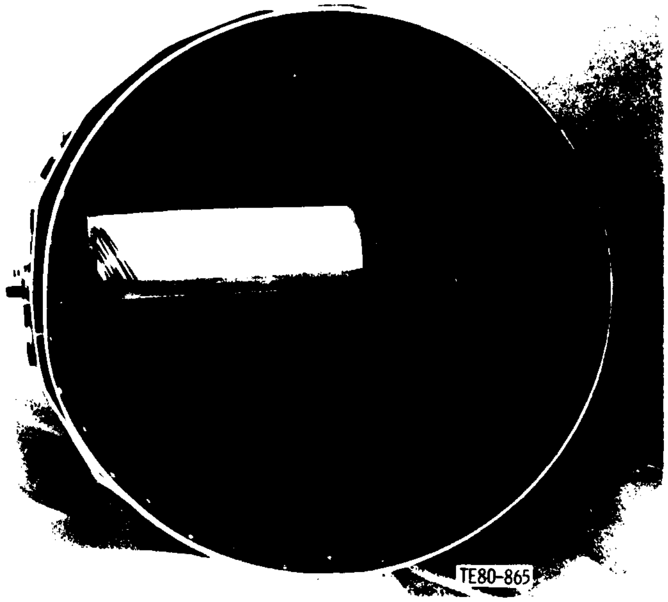

Figure 4. Burner-to-cascade inlet transition duct.

The cascade inlet instrumentation is located in the rectangular inlet section. A schematic of the cascade and inlet section showing the relative position of the inlet instrumentation is shown in Figure 5. Inlet core rakes are located 6.72 inches (~3 1/4 axial chords) upstream of the vane leading edge plane. Pressure rakes are located midway between vanes 1 and 2, and midway between vanes 3 and 4. Similarly, temperature rakes are located midway between vanes 2 and 3 and also 4 and 5. These rakes provide measurements 1/2 inch from each wall, and at 1/2 inch spanwise intervals.

Inlet boundary layer rakes were installed in the rectangular inlet section on the same endwall that provided the heat flux and passage static pressure measurements in the cascade. The centers of these rakes were located 4.29 inches (~2 axial chords) upstream of the vane leading edge plane. Total pressure rakes, like the one in Figure 6, were located inline with the leading edge of vanes 2 and 4, while the single boundary layer temperature rake was inline with the leading edge of vane 3. These rakes provided measurements at sixteen locations throughout the first 1/2 inch of span. As the test program progressed, elements on the boundary layer rakes began to fail, making it necessary to install a traversing inlet probe. This probe, shown in Figure 7, contained a single temperature and pressure element and could be rotated from the wall out to midspan by a computer controlled traverse system. The pitot type pressure element did require calibration to account for air angle effects on the pressure reading. The tip of this probe was located at a nominal position of 5.01 inches (~2 1/2 axial chords) upstream of the vane leading edge plane. In the vertical plane, the center of the probe was located 0.78 inches above the upper inlet core pressure rake.

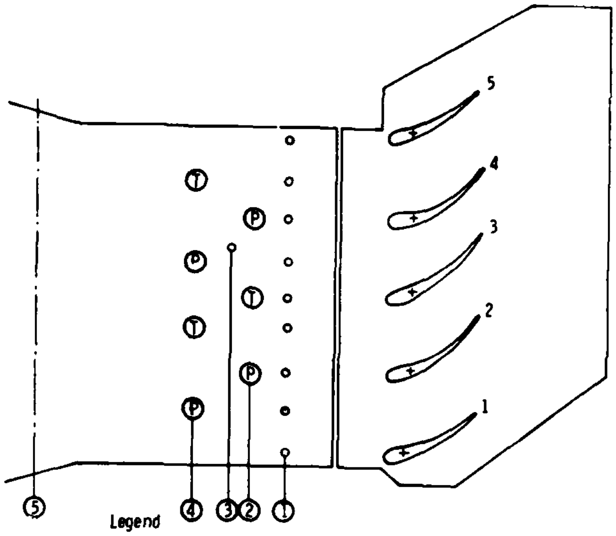

Figure 5. Cascade inlet instrumentation schematic.

The final inlet instrumentation consists of a row of static pressure taps located on the same wall as the boundary layer rakes. These are positioned 3.19 inches (1 1/2 axial chords) upstream of the vane leading edge plane. The nine taps are located in the vertical plane so that they line up alternately with the vane leading edge and the midpassage point.

In addition to the inlet instrumentation, Figure 5 also indicates the position of the boundary layer trip tubes. These 3/8-inch diameter tubes were located upstream of the start of the rectangular section. They are 13.0 inches upstream of the vane leading edge plane. These tube locations were also used to inject steam required to produce the distorted inlet pressure and temperature profiles for the Phase II tests.

3.2.3 Cascade Description

The linear cascade employed five vanes characteristic of an advanced first-stage core turbine. The vane coordinates, including leading and trailing edge radii, are given in Table 2. Figure 8 illustrates the relationship between the coordinate system in Table 2 and the aerodynamic reference plane (cascade axis).

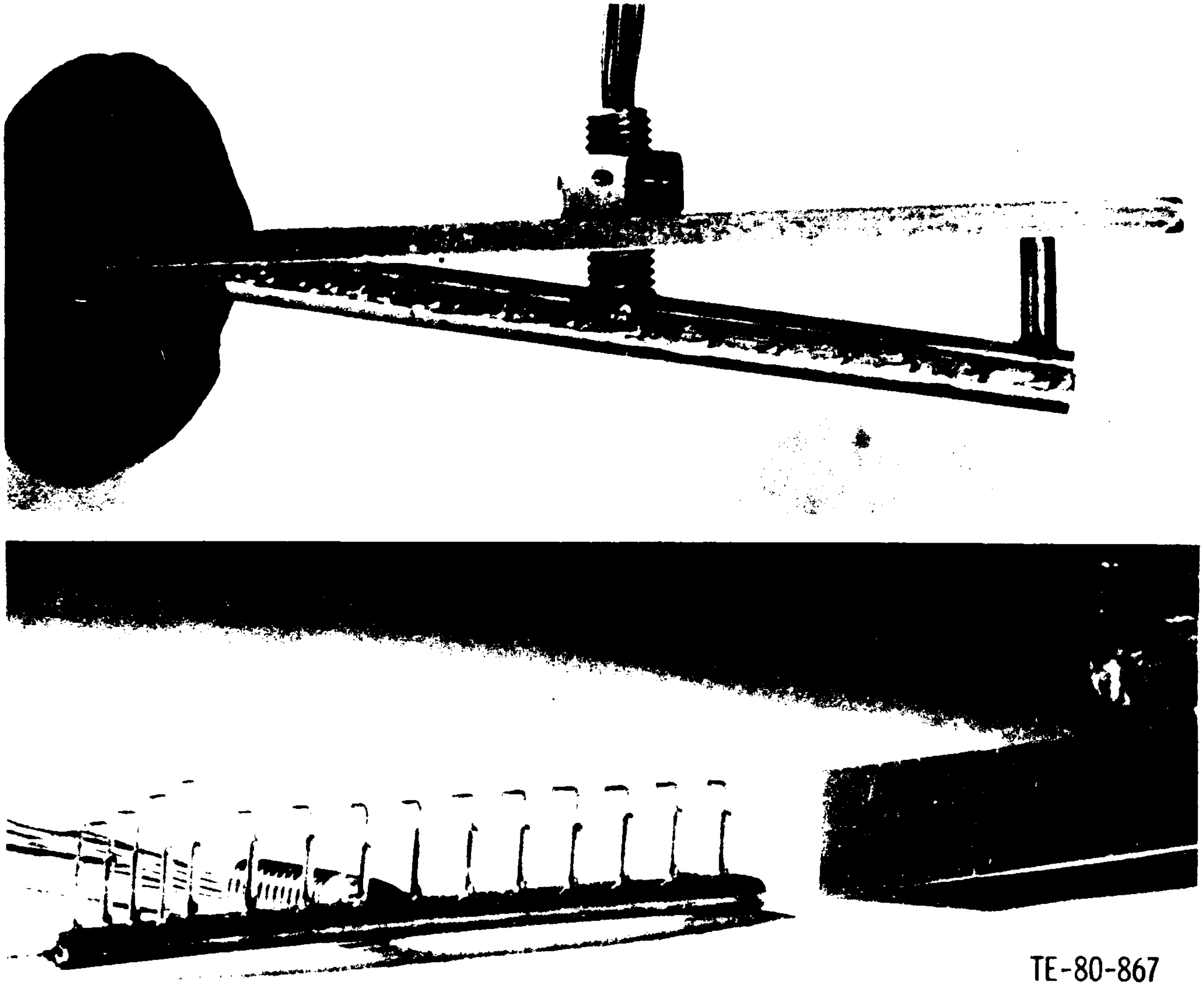

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Figure 6. Inlet boundary layer total pressure rake.

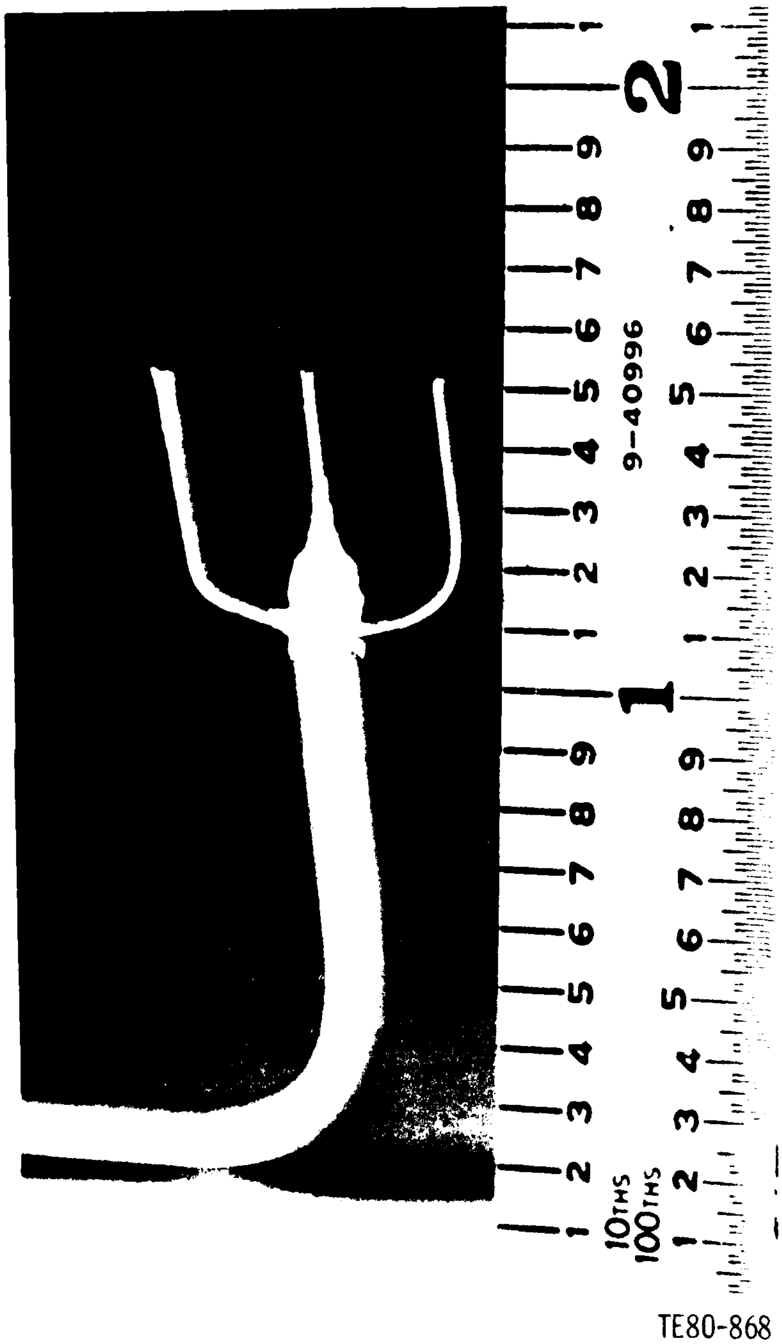


Figure 7. Traversing inlet total pressure and temperature probe.

TABLE 2. LINEAR CASCADE VANE COORDINATES

Theta = -57.95° Leading radius = 0.210 in. Trailing radius = 0.045 in.

Station	X (inches)	Y (inches)	Station	X (inches)	Y (inches)
1	-1.2916	-0.2942	31	2.3780	-0.2942
2	-1.2871	-0.2505	32	2.3270	-0.3388
3	-1.2445	-0.1190	33	2.2085	-0.3233
4	-1.1724	0.0011	34	2.0900	-0.3087
5	-1.0742	0.1010	35	1.9713	-0.2952
6	-0.9560	0.1763	36	1.8525	-0.2826
7	-0.8253	0.2270	37	1.7336	-0.2710
8	-0.6882	0.2568	38	1.6147	-0.2605
9	-0.5485	0.2704	39	1.4956	-0.2509
10	-0.4081	0.2721	40	1.3765	-0.2425
11	-0.2679	0.2657	41	1.2572	-0.2351
12	-0.1280	0.2538	42	1.1380	-0.2288
13	0.0116	0.2381	43	1.0186	-0.2237
14	0.1508	0.2197	44	0.8992	-0.2198
15	0.2897	0.1991	45	0.7798	-0.2171
16	0.4282	0.1766	46	0.6604	-0.2158
17	0.5666	0.1526	47	0.5409	-0.2159
18	0.7047	0.1274	48	0.4215	-0.2176
19	0.8427	0.1011	49	0.3021	-0.2210
20	0.9804	0.0740	50	0.1828	-0.2262
21	1.1180	0.0461	51	0.0635	-0.2335
22	1.2555	0.0174	52	-0.0555	-0.2431
23	1.3928	-0.0120	53	-0.1743	-0.2554
24	1.5299	-0.0423	54	-0.2928	-0.2708
25	1.6668	-0.0735	55	-0.4107	-0.2899
26	1.8034	-0.1059	56	-0.5278	-0.3133
27	1.9397	-0.1396	57	-0.6437	-0.3421
28	2.0756	-0.1748	58	-0.7578	-0.3774
29	2.2111	-0.2119	59	-0.8689	-0.4211
30	2.3458	-0.2510	60	-0.9758	-0.4758

The cascade consists of five airfoils, positioned as shown in Figure 9. The cascade and airfoil parameters are given in Table 3. The airfoils were mounted cantilevered from the heat transfer endwall as shown in Figure 10, and did not pass through the opposite endwall. All vanes were internally cooled by multiple pass convection air cooling. The outer two vanes, numbers 1 and 5, carried no instrumentation, but served as sidewalls for the cascade. A gap of approximately 0.100 inch existed between the cascade inlet sidewall and vanes 1 and 5. Previous experience with similar cascades with this particular airfoil indicated this gap was required to produce periodicity across the passages. Vanes 2 and 4 carried static pressure taps on the pressure and suction surfaces respectively. Vane 3 was instrumented for heat transfer measurements. Details of the vane instrumentation are given in Section 3.2.5.

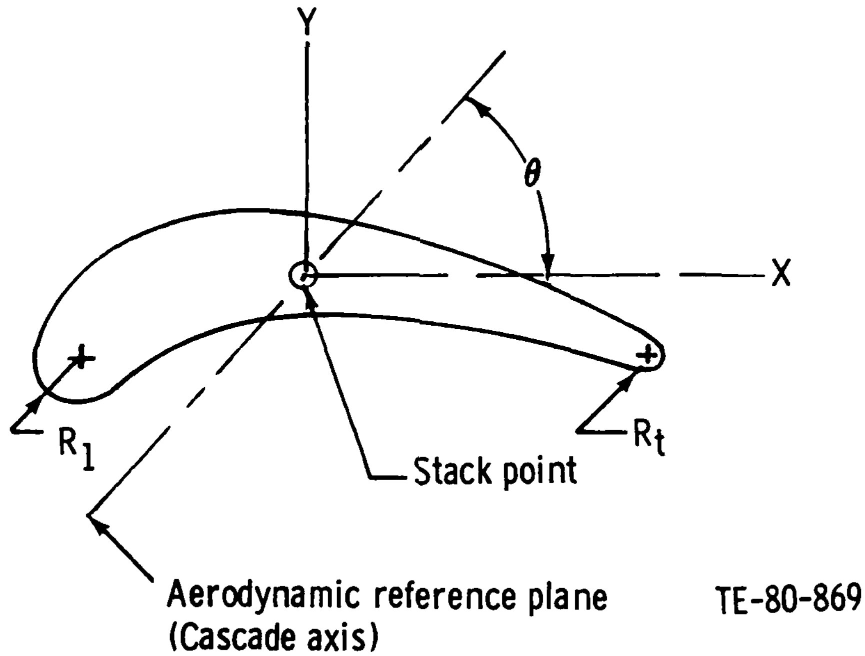


Figure 8. Relationship of vane geometry and cascade coordinate systems.

TABLE 3. LINEAR CASCADE AIRFOIL DESCRIPTION

Axial chord	2.067
True chord	3.6697
Setting angle	-57.95 deg
Air exit angle	71.3 deg
Throat height	0.8356 in.
Cascade blade height	3.000 in.
Spacing	2.660 in.

Both endwalls were cooled with the aid of copper heat sinks, shown in Figure 10. Cooling was provided by a combination of water cooling tubes attached to the heat sinks and by steam flowing freely past the heat sink in the pressure shell around the cascade. The purpose of the heat sinks was to minimize temperature gradients on the endwalls. This, in turn, reduced the density of thermocouples required to measure the temperature field on the cooled side of the heat transfer endwall. The passage between vanes 2 and 3 was instrumented with thermocouples on both the hot and cold surfaces in order to employ the heat transfer measurement technique described in Section 3.1. The passage between vanes 3 and 4 was instrumented with static pressure taps. The details of endwall instrumentation are given in Section 3.2.4.

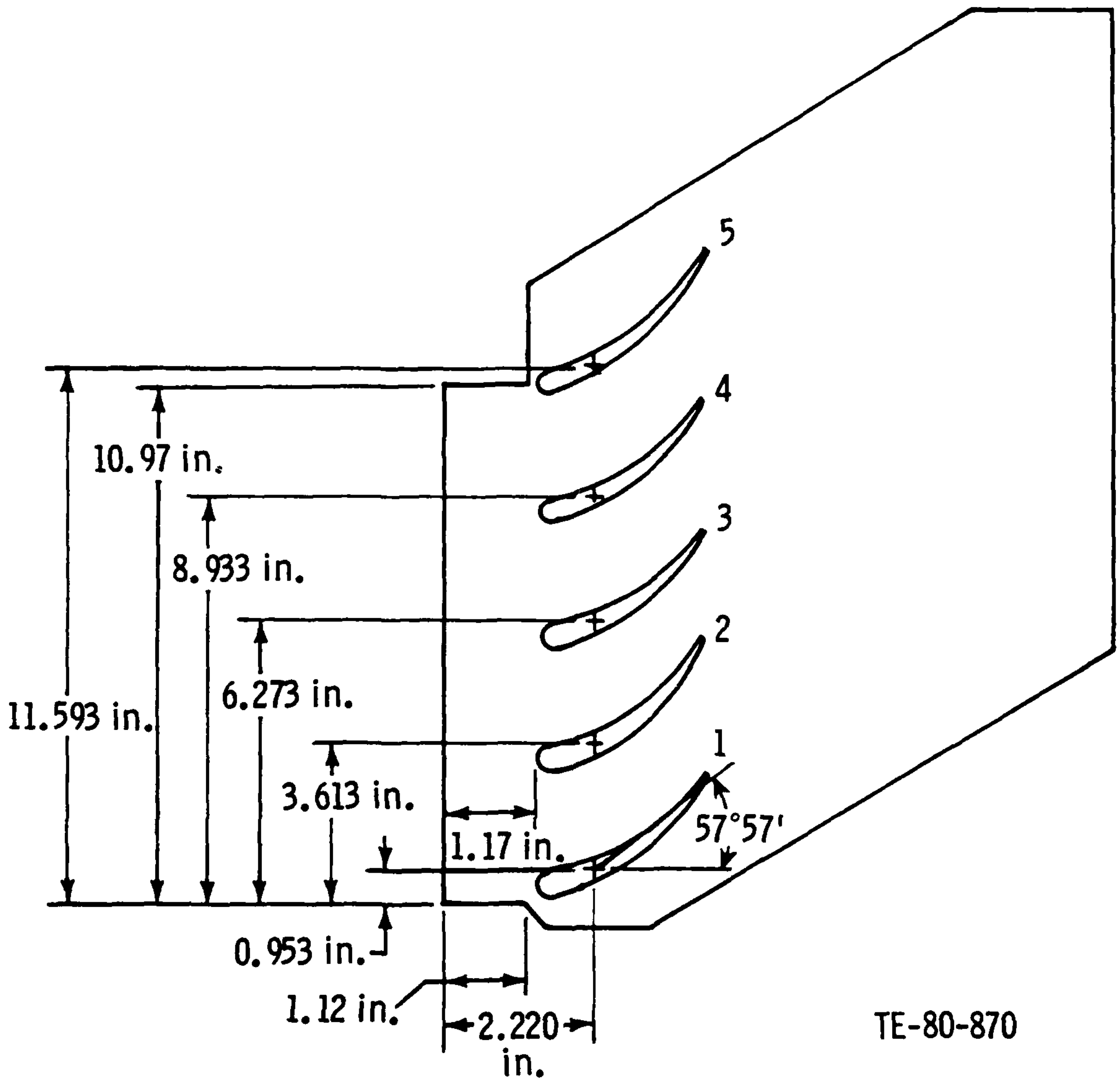


Figure 9. Airfoil locations in cascade.

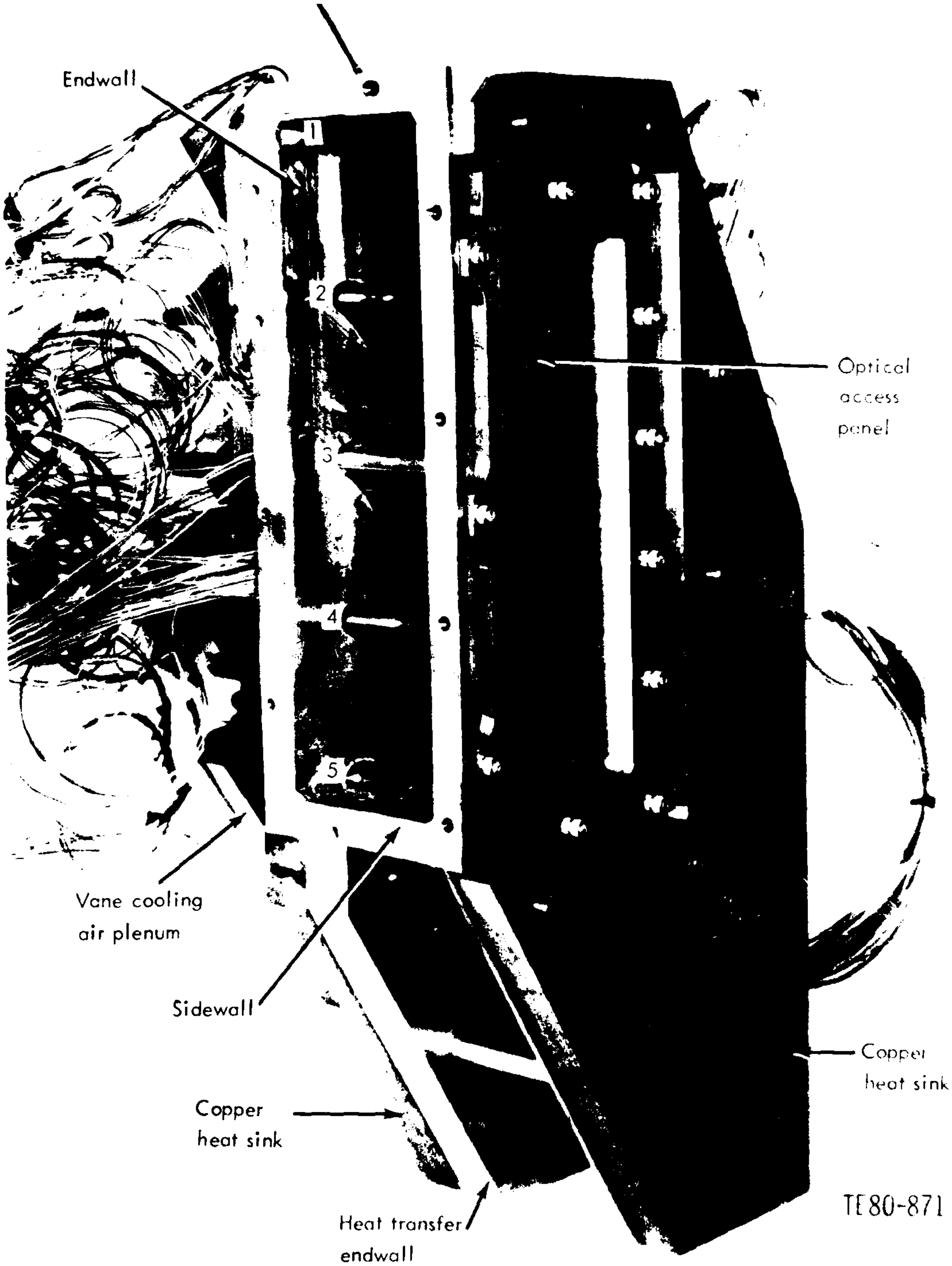


Figure 10. Cascade assembly.

The opposite endwall served two purposes. As shown in Figure 10, this endwall contains an optical access panel. The metal plate installed for heat transfer tests was removed and replaced with a quartz window in order to make inlet turbulence measurements with the laser doppler anemometer (LDA). The details of this technique are given in Section 3.2.7. As a result of changes made during the contract, it became necessary to make adiabatic wall temperature measurements on this same endwall. Consequently, a new endwall was designed and fabricated and was used to make the adiabatic wall measurements. Details of this design are given in Section 3.2.4.

3.2.4 Endwall Instrumentation

The heat transfer endwall shown in Figure 10 was fabricated from nickel and was 1.00 inch thick. This combination of material thickness and thermal conductivity provided temperature differences through the wall that were large enough (50-100°F) to minimize thermometry errors. In addition, the relatively thick wall resulted in negligible errors being introduced by the surface grooves required to install the thermocouples. This design ensured that a minimum error would result from the heat transfer measurement technique described in Section 3.1.

Figure 11 shows the installation of 53 0.020-inch diameter sheathed thermocouples on the hot side of the heat transfer endwall. This photo was taken just before the thermocouples and grooves were covered with cement to provide a smooth endwall surface. A similar, but less dense, pattern of 31 thermocouples was installed on the cooled backside of the heat transfer endwall. The passage instrumented with the thermocouples for the heat transfer measurements is between vanes 2 and 3 in Figure 10. The relative position of thermocouples on the hot gas side and cooled backside are shown in Figures 12 and 13 respectively. Dimensions for the exact locations of the endwall thermocouples are given on the sample computer data output sheets in Appendix B. Those dimensions are referenced to the lower thermocouple in the inlet plane. The relation between the reference thermocouples and the vane stacking axis are given in Figures 12 and 13.

The passage and exit plane static pressure tap locations can be seen in Figure 11. This photo was taken at an intermediate step during the installation. The tubes shown extending through the wall were brazed in place and then machined smooth with the surface as shown in Figure 14. A total of 42 static taps were installed at eight axial positions throughout the passage. Taps were installed near the pressure and suction surfaces of the vanes and at approximately 25% intervals across the passage. The static tap positions are illustrated in Figure 15 with dimensions of the tap locations given relative to the vane 3 stacking axis in Table 4.

The photo in Figure 14 shows the vanes installed in the heat transfer endwall. Close examination of the photo shows a gap between the vanes and endwall that extends completely around the vanes. This 0.040-inch gap was filled with a low thermal conductivity (0.40 Btu/hr ft^2 °F) ceramic cement during final assembly. This was done to thermally isolate the vane and endwall, in order that they could be considered as separate problems for the heat transfer measurement technique outlined in Section 3.1.

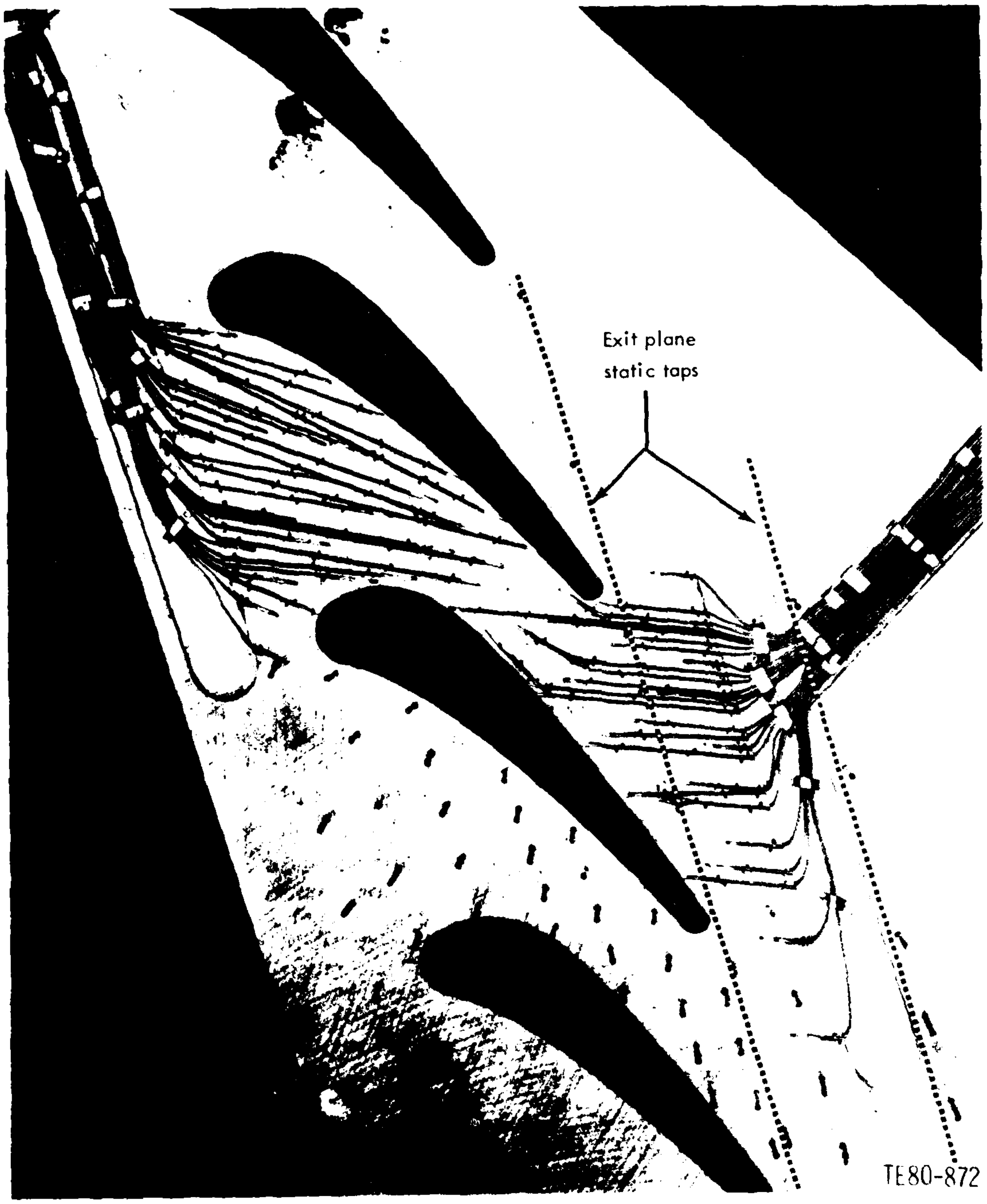


Figure 11. Heat transfer endwall temperature and pressure instrumentation.

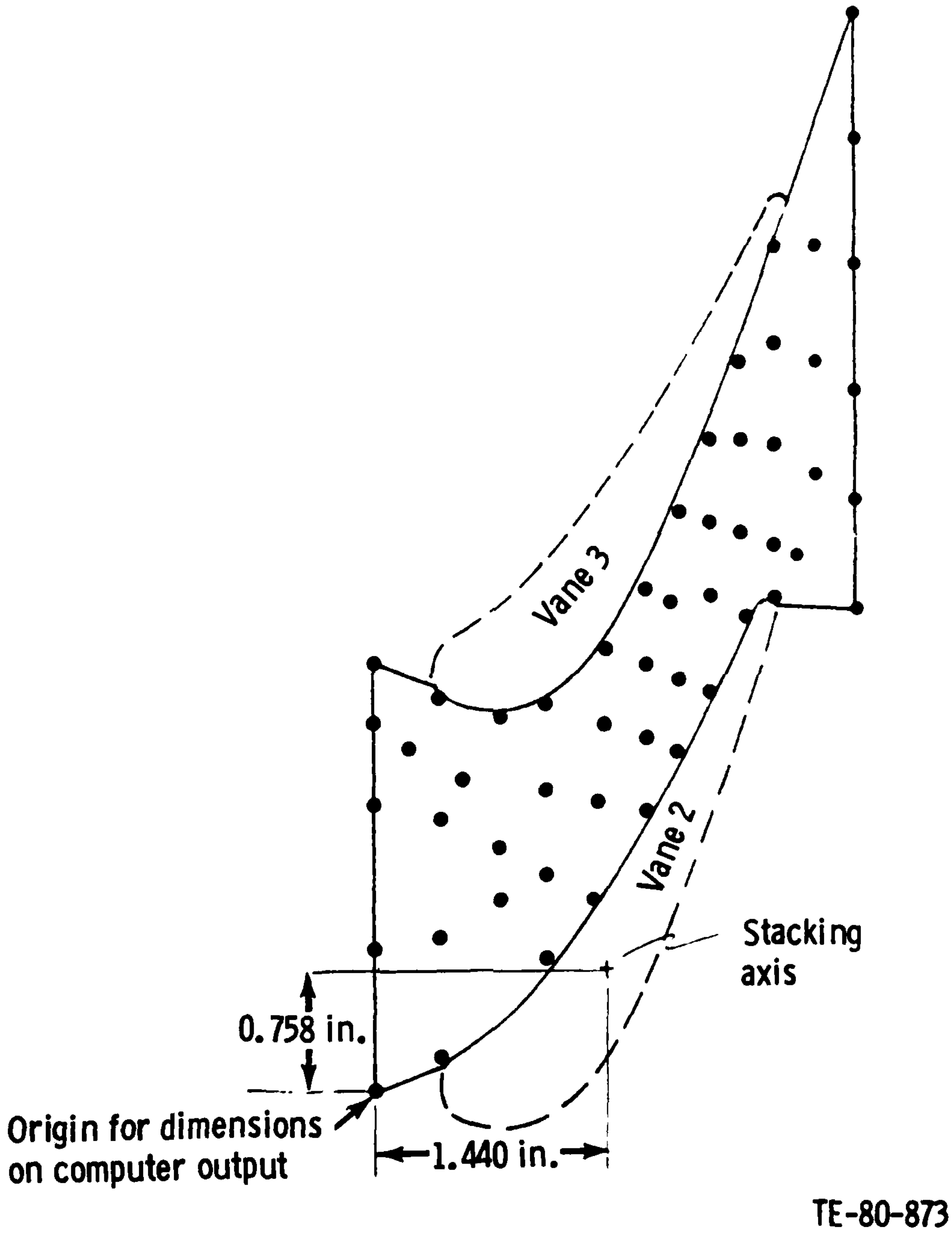


Figure 12. Relative thermocouple locations for hot gas side of heat transfer endwall.

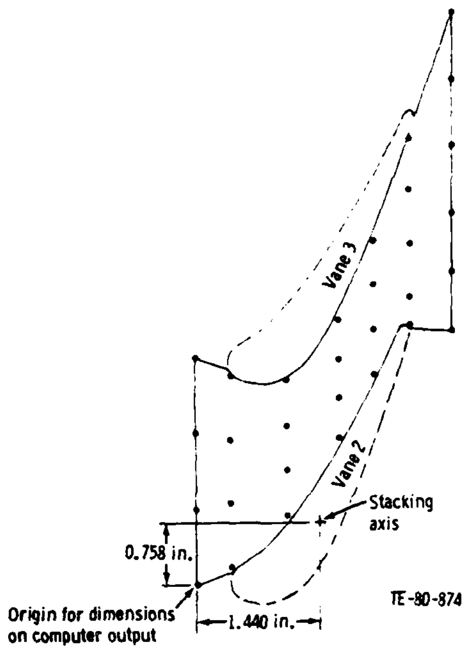


Figure 13. Relative thermocouple locations for cooled backside of heat transfer endwall.

TABLE 4. ENDWALL PASSAGE STATIC PRESSURE TAP LOCATION RELATIVE TO STACKING AXIS OF VANE 3 (FIGURE 15)

Axial station	1	2	3	4	5	6	7	8
x (in.)	-1.440	-1.031	-0.532	-0.032	0.318	0.718	1.034	1.534
y (in.)	-0.683	-0.484	-0.070	0.604	1.192	1.972	2.700	2.184
	-0.093	0.043	0.333	0.918	1.509	2.332	3.108	2.872
	0.572	0.570	0.735	1.232	1.826	2.692	3.515	3.560
	1.237	1.097	1.138	1.546	2.143	3.052	3.923	4.095
	1.902	1.624	1.540	1.860	2.460	3.412	4.330	4.630
								5.165
								5.700

During the contract, the endwall opposite the heat transfer endwall was rebuilt in order to add the capability of measuring adiabatic wall temperatures in the passage. Recall from Section 3.2.3 that the vanes are cantilevered from the heat transfer endwall. This results in a slight gap (0.004 inch) between the vane tip and the opposite endwall, as can be seen in Figure 16. Since the original statement of work did not require measurements on this endwall, the gap was acceptable. However, in order to make the adiabatic endwall measurements on this endwall, it was necessary to weld extensions on vanes 3 and 4 so that they extended through the wall. This eliminated the possibility of tip leakage from the pressure to suction surface of the vane, which could

Figure 14. Installation of airfoils in heat transfer endwall.

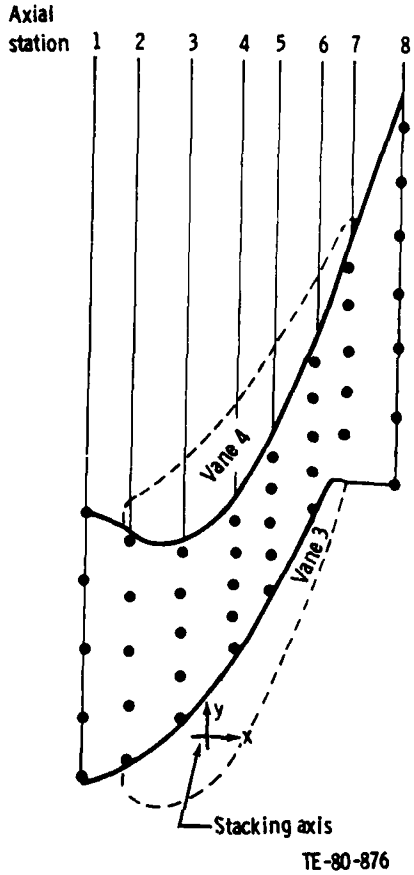


Figure 15. Relative static pressure tap locations on heat transfer endwall.

alter the secondary flow structure locally and thereby result in incorrect values in adiabatic endwall temperatures.

A schematic of the adiabatic endwall design is shown in Figure 17. An adiabatic endwall "pan" was fabricated to cover the passage between vanes 3 and 4 and portions of the two adjacent passages. The portion of the pan that served as the endwall was fabricated from 1/16-inch thick, 300 series stainless steel. Vanes 3 and 4 extended through the endwall and were sealed with low thermal conductivity ceramic cement to thermally isolate them from the endwall. A trial installation of the pan showing the vane-endwall gap before cement was applied is shown in Figure 18.

As indicated in Figure 17, thermocouples were installed on the back side of the adiabatic endwall. It was necessary to install them on the back side since the thin wall did not permit cutting of grooves on the hot side. Figure 19 shows the pan after the 90 adiabatic endwall passage thermocouples were installed. While the entire passage was heavily instrumented, the thermocouples were concentrated in the vane leading edge suction surface region and near the vane suction surface downstream of the throat in an attempt to better define the temperature patterns in areas most affected by the secondary flow structure. The locations of the thermocouples are illustrated in Figure 20.

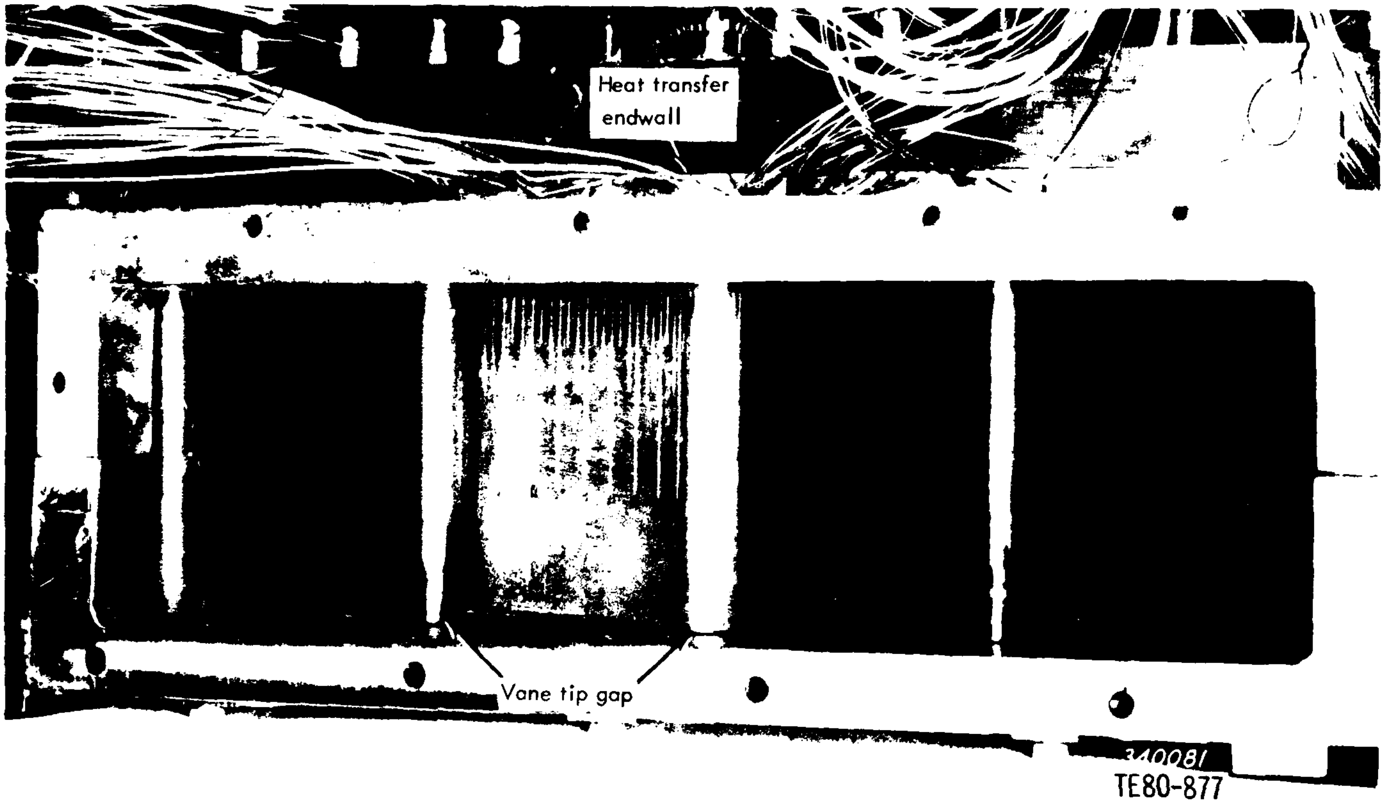


Figure 16. Inlet view of cascade.

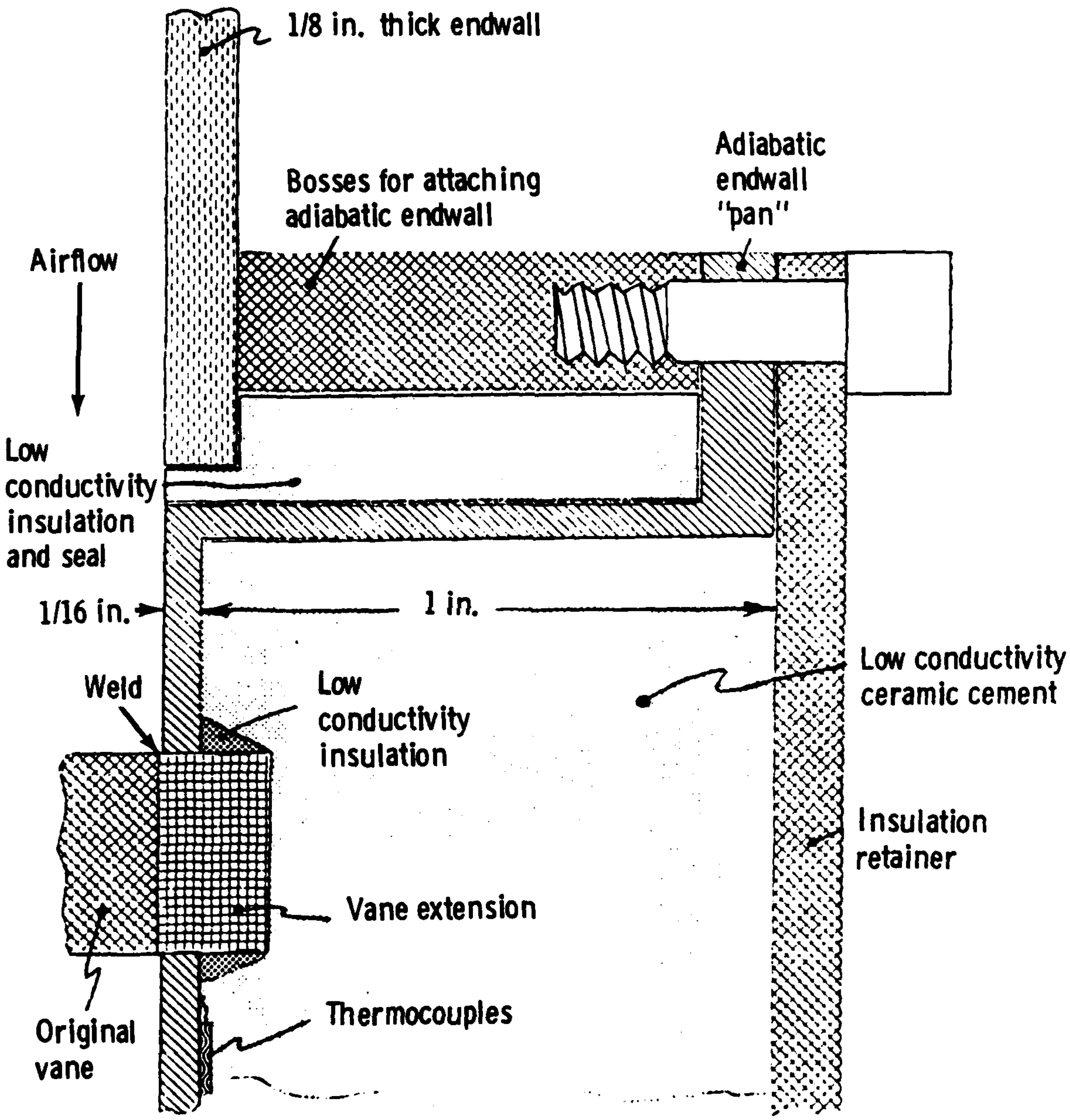


Figure 17. Schematic of adiabatic endwall with vane extension.

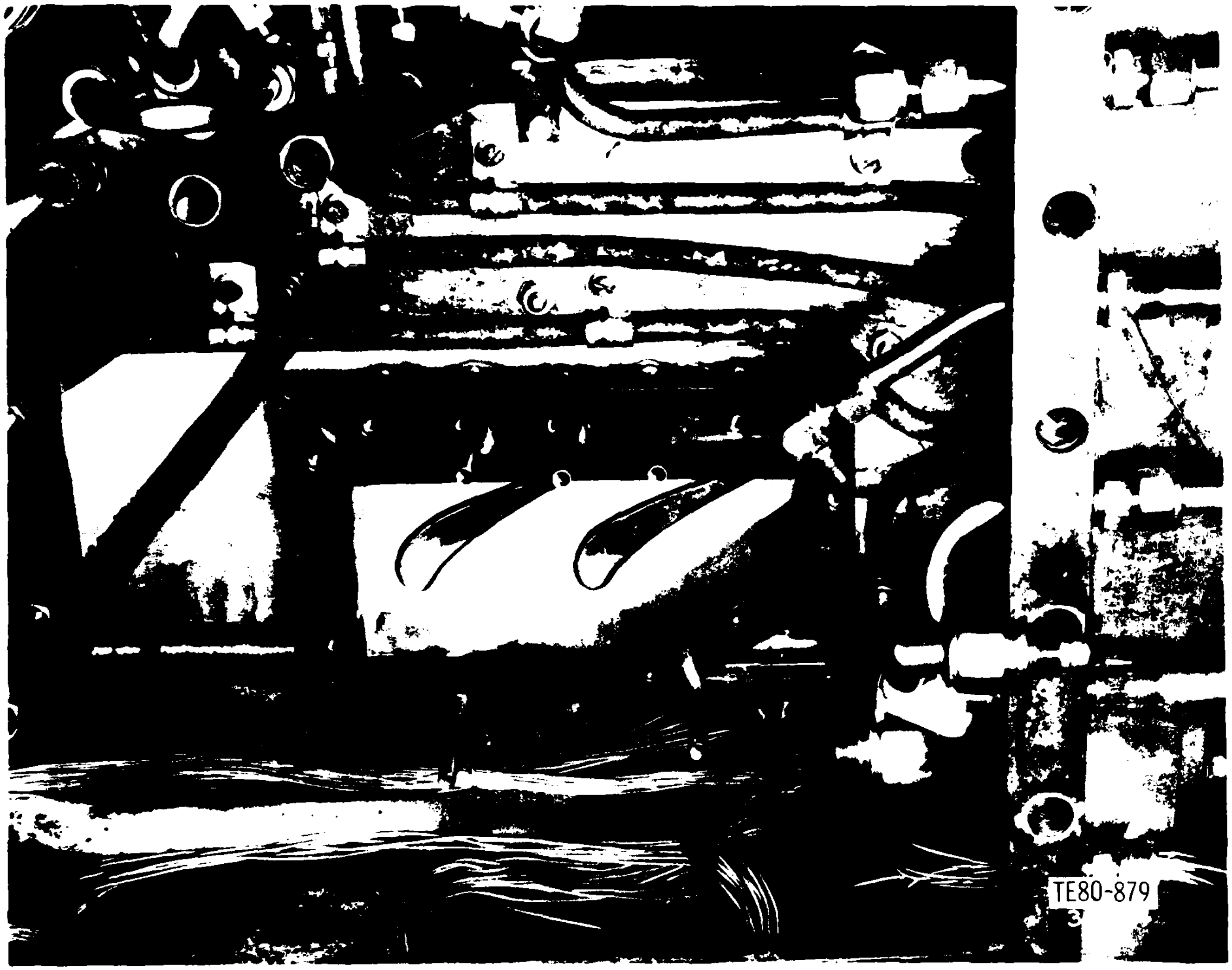


Figure 18. Trial installation of adiabatic endwall pan.

Figure 19. Adiabatic endwall temperature instrumentation.

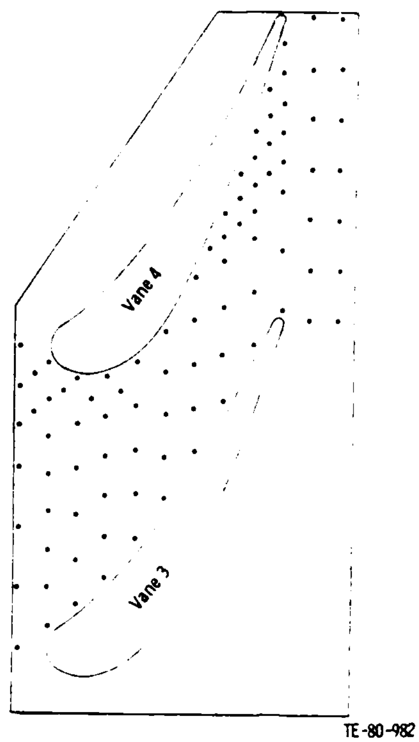


Figure 20. Relative thermocouple locations for adiabatic endwall.

Dimensions for the exact locations of the thermocouples are given on the sample computer data output sheets in Appendix B. The origin for those dimensions has the same relationship to the vane stacking axis as the origin for the heat transfer endwall shown in Figure 12, except it is relative to the stacking axis of vane 3 rather than vane 2.

The adiabatic condition was maintained by filling the pan with a 1-inch thick layer of low conductivity insulation which was held in place by a retainer.

The adiabatic condition was checked periodically by monitoring two thermocouples located at different depths in the insulation. In addition, the pan was isolated from the main endwall by a gap, which was sealed with the same low thermal conductivity cement that was used to seal around the vanes. This prevented errors near the edge of the pan due to contact with the main endwall section. This design, shown schematically in Figure 17, appears to have provided good adiabatic endwall data.

3.2.5 Vane Instrumentation

Three of the five vanes in the linear cascade are instrumented. The center vane (vane 3) carries interior and exterior surface thermocouples for heat transfer measurements. Vanes 2 and 4 (see Figure 10) carry instrumentation for determining the pressure profiles around the vanes.

Vane 2 has static pressure taps on the pressure surface and vane 4 has static taps on the suction surface. The pressure measurements were split in this manner in order to limit all measurements to the center two passages in the cascade. Figure 21 shows the interior of vane 2 with the pressure lines installed. The vanes were cut open, the 0.020-inch OD miniature tubing inserted through the wall, brazed in place, and polished smooth with the exterior surface. The vanes were then welded back together.

Pressure taps were located at three spanwise planes on both vanes 2 and 4. Measurements were made at 5%, 20% and 50% of span. Measurements were made at 22 locations around the vane at each of the three spanwise planes. Locations at each plane were identical and are shown in Figure 22.

Vane 3 was instrumented with interior and exterior surface thermocouples in an attempt to measure vane heat transfer. Chromel-alumel 0.020-inch diameter, sheathed thermocouples were installed in surface grooves, which, after installation of the thermocouples, were filled and polished to provide a smooth surface. Figure 23 shows vane 3 after cutting of the interior and exterior grooves. The vane was cut apart near the leading and trailing edges in order to install the internal thermocouples, just as the pressure tap vanes were in Figure 21. The installation of grooved thermocouples in thin sections (such as with this vane) requires corrections to thermocouple readings in order to determine correct surface temperature. The required corrections are described in Reference 8.

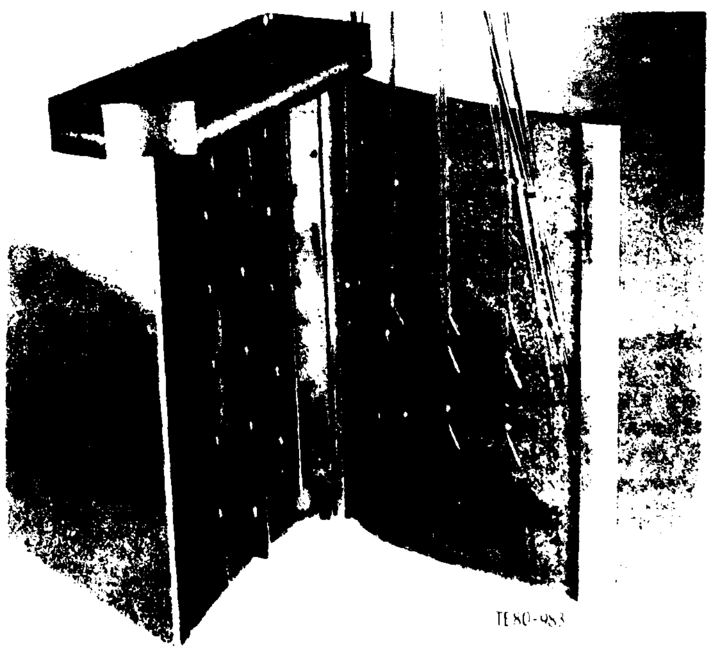


Figure 21. Vane 2 interior showing static pressure instrumentation.

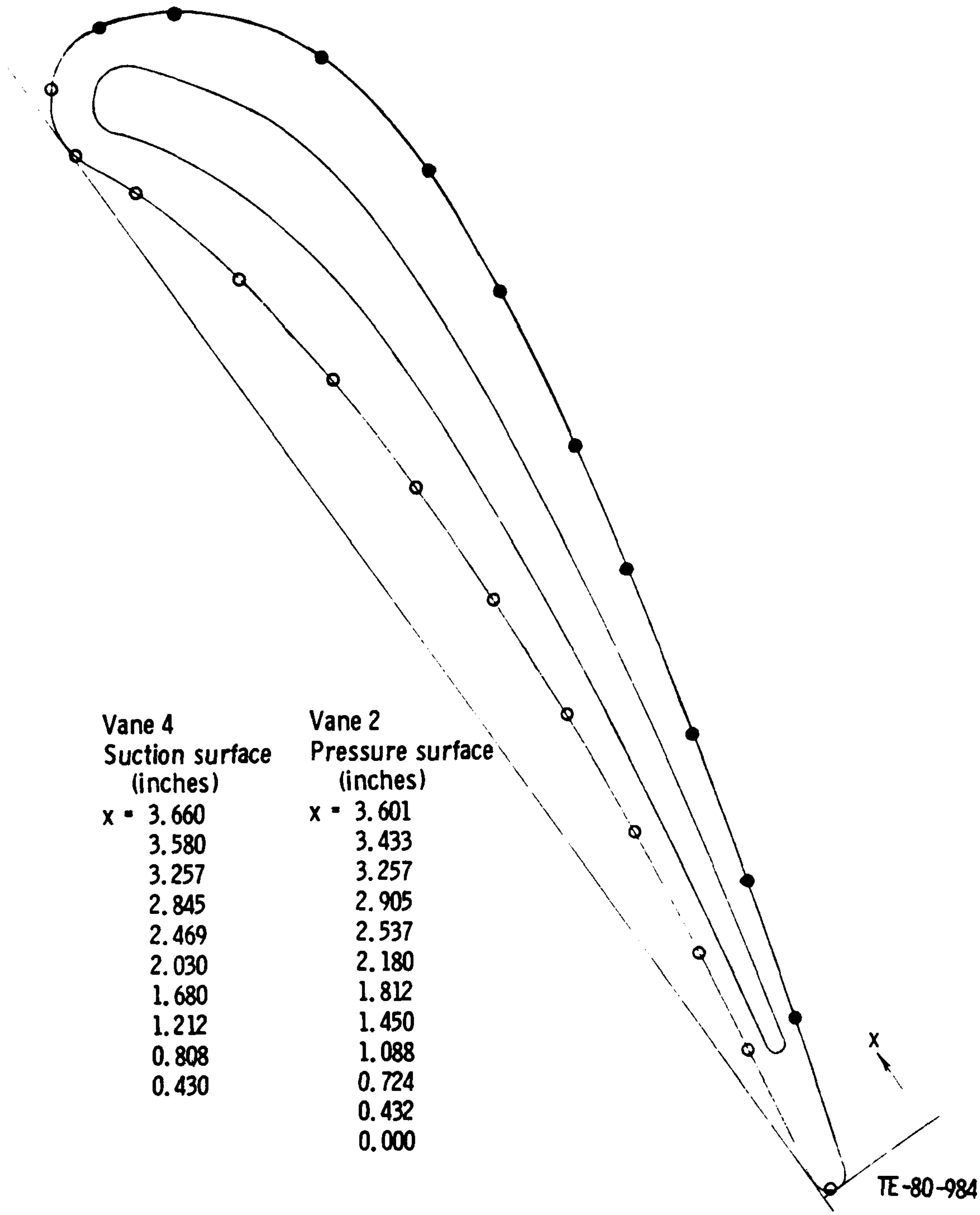


Figure 22. Vane static pressure tap locations.

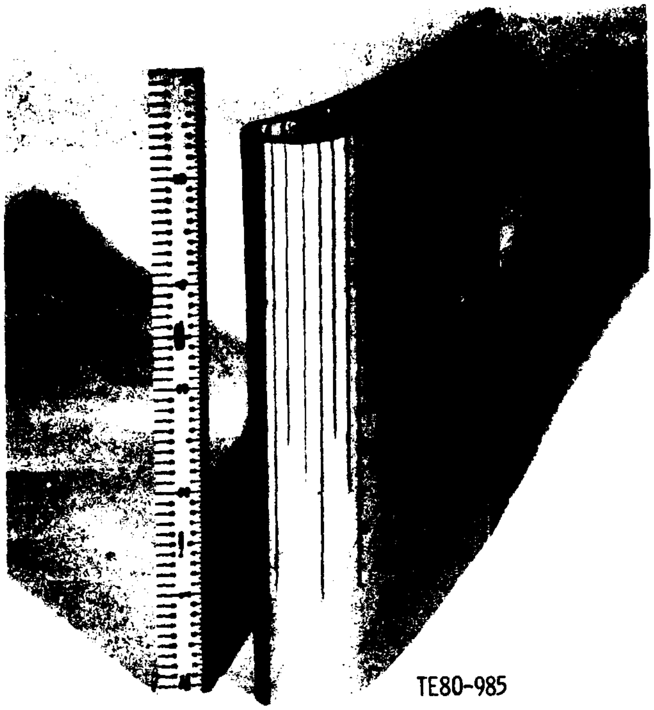


Figure 23. Vane 3 exterior and interior thermocouple grooves.

As with the pressure tap vanes, temperatures were measured at three spanwise planes located at 5%, 20% and 50%. The finished vane is shown in Figure 24. Because the grooves run straight out to the end of the vane, it is not possible to locate thermocouples at the same chordwise position at each of the three spanwise planes. The locations of the interior and exterior thermocouples at each of the three spanwise planes are illustrated in Figure 25. The locations of the thermocouples, as a percent of true chord measured from the leading edge, are given on the sample computer data output sheets in Appendix B.

3.2.6 Instrumentation for Aerodynamic Loss Measurements

The cascade was designed to include provisions for a survey of the exit flow field. Figure 14 shows the exit probe slot for access of the traversing probe. Also shown are the two rows of exit endwall static pressure taps.

Exit surveys of this type, using miniature aerodynamic probes, have been done routinely in the ACF. The probe used to acquire data for this program was a 5-port, truncated cone probe. These probes are calibrated in a small instrumentation tunnel up to a Mach number of 1.6. They provide five output parameters: Mach number, total pressure, static pressure, and pitch and yaw flow angle components (spanwise and circumferential). When aligned close to the streamwise flow, the 0.125-in. diameter cone probe provides very low blockage and does not appreciably disturb the flow field. Special methods have been developed to correct the probe readings when the probe is in a shear flow region, such as in the vane wake. Data repeatability indicates the probe accuracies to be about 0.25% for total pressure, 1.0% for static pressure, and

Figure 24. Finished vane instrumented with thermocouples.

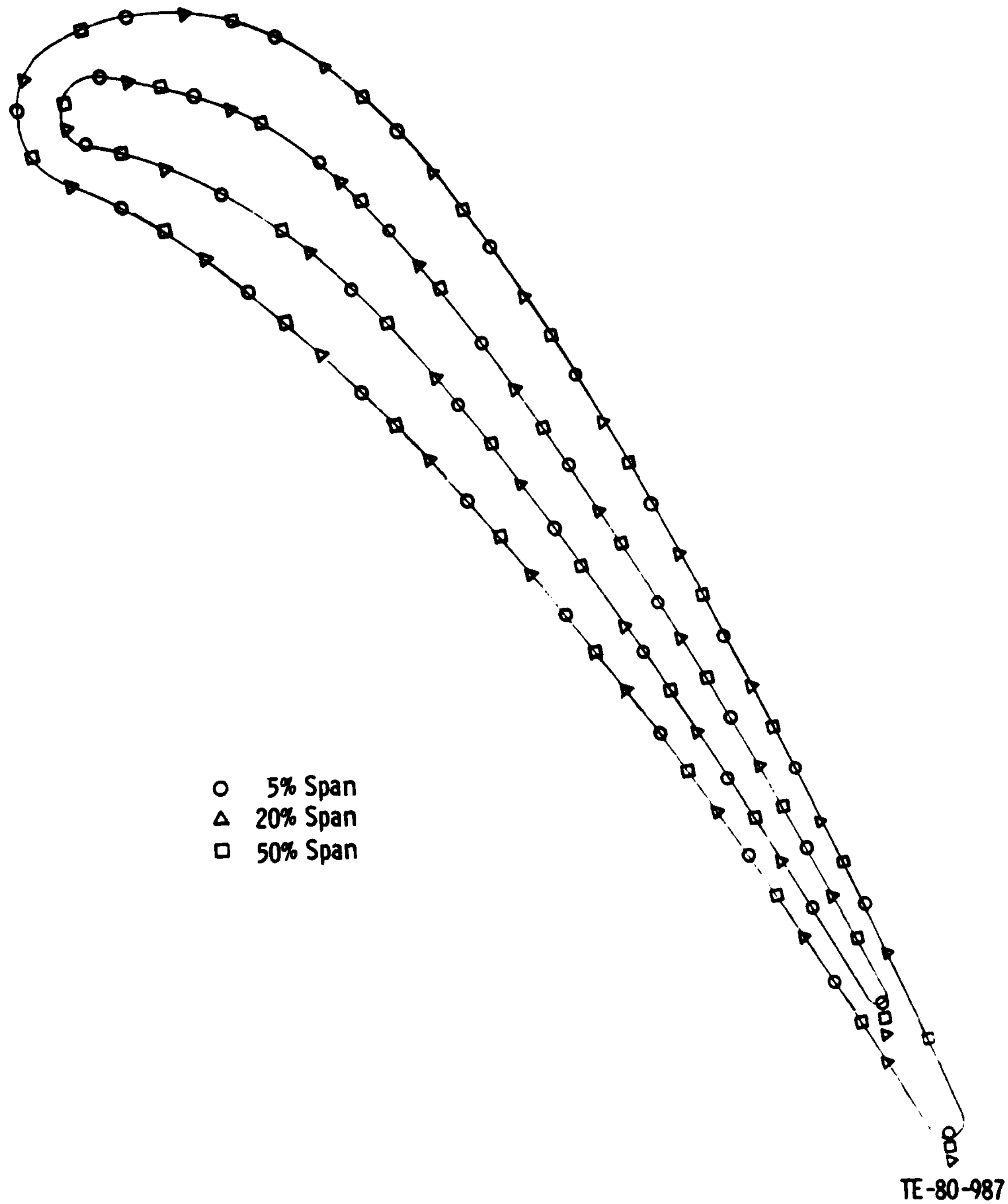


Figure 25. Relative location of exterior and interior thermocouples.

1% for Mach number, except when the flow is very near sonic. The angular sensitivity is better than 0.25 degree, but the physical setup of the probe in the traverse unit increases the angular uncertainty to 1.0 degree in the absolute reference. Mass flow balance checks between the uniform inlet and the integrated exit survey usually check within 3-5%, and a part of this difference can be attributed to the change in endwall boundary layer thickness through the cascade.

A special exit rake consisting of a cone probe and a radiation-shielded total temperature probe was constructed to perform the exit flow surveys in this program. It is shown in Figure 26. The probe was installed through the exit probe slot in Figure 14, so that the probe was aligned with the exit air angle. The probe tip was located 1.393 inches (0.67 axial chords) downstream of the vane trailing edge. This was directly above the second row of endwall exit static pressure taps. The first row was located 0.142 inch downstream of the vane trailing edge. A three dimensional traverse system was utilized with the exit probe. It was initially utilized to align the probe with the exit air angle, and then used in a 2-D mode to provide circumferential (cross passage) and spanwise traverse to acquire the exit flow field data. These traverses were made behind the center vane in the cascade.

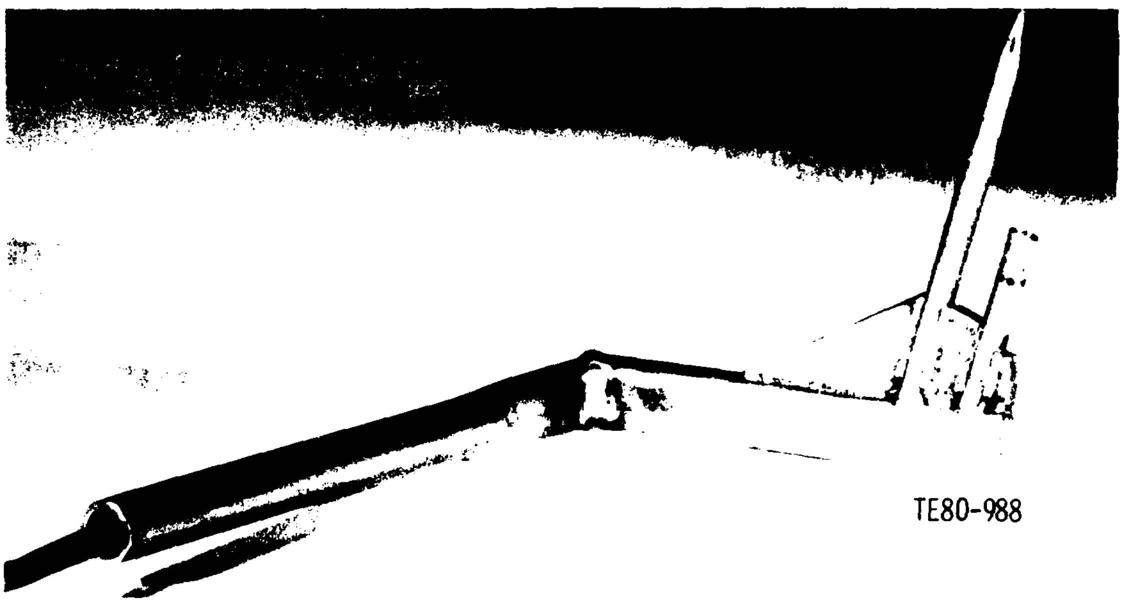


Figure 26. Exit cone probe and total temperature probe.

3.2.7 Inlet Turbulence Measurements

As discussed in Section 3.2.3, the cascade was designed with a removable optical access panel, shown in Figure 10, which can be replaced with a quartz window. By similarly installing a window in the facility pressure shell, it is possible to view the cascade during operation of the facility. The axial field of view through the access panel includes an area from 0.170 inch forward of the vane leading edge, to approximately 0.75 inch downstream of the trailing edge. In the circumferential direction the entire passage between vanes 2 and 3 can be viewed, as well as nearly 90% of the adjacent passages.

This optical access allowed the use of a laser doppler anemometer (LDA) to measure turbulence intensity levels at the inlet of the cascade. The LDA is the only instrument that satisfies the requirements of not disturbing the flow under measurement, being insensitive to the effects of high-temperature corrosive gases, and having good frequency response.

The arrangement of the components of the LDA system is shown in Figure 27. The mode of operation is as follows (refer to Figure 27): The laser light of wavelength λ (0.5145 μ) is split into two equal-intensity, parallel beams. The two beams are brought to focus at the focal length of the transmitting lens, f_t, and at this point form an interference fringe pattern with fringe spacing d. The two converging beams form an ellipsoidal volume containing these fringes at the intersection region. A particle passing through this ellipsoid scatters light into a sphere surrounding the particle, and the

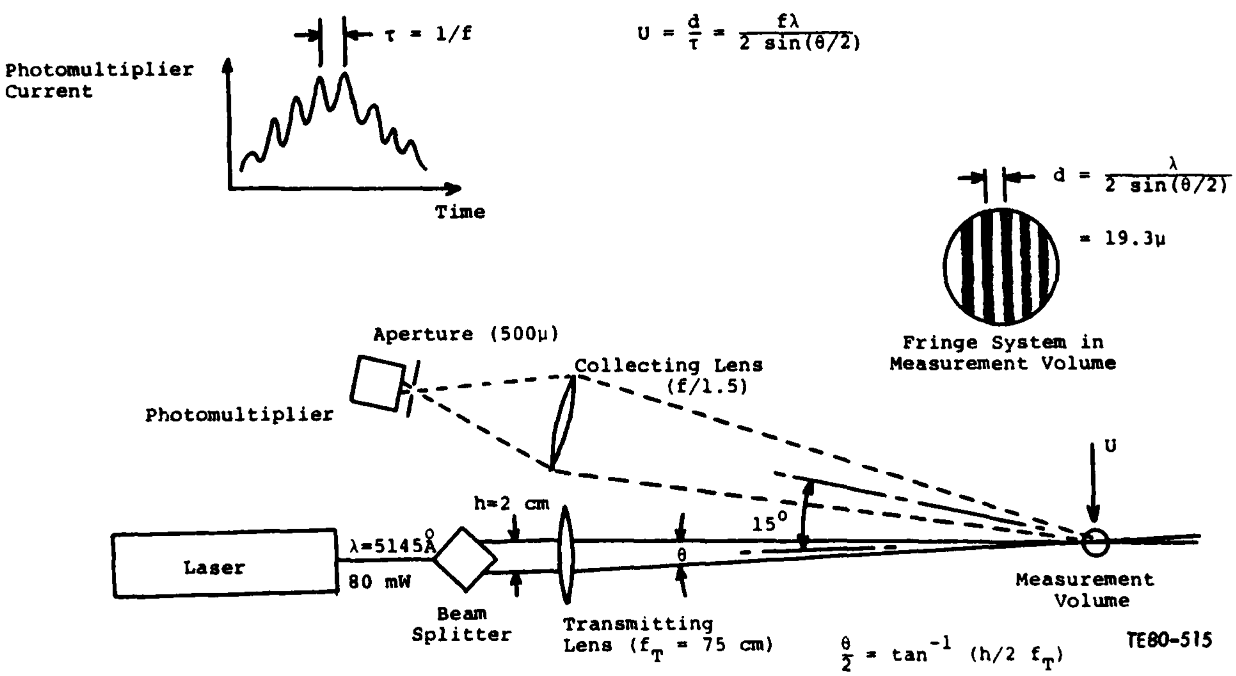
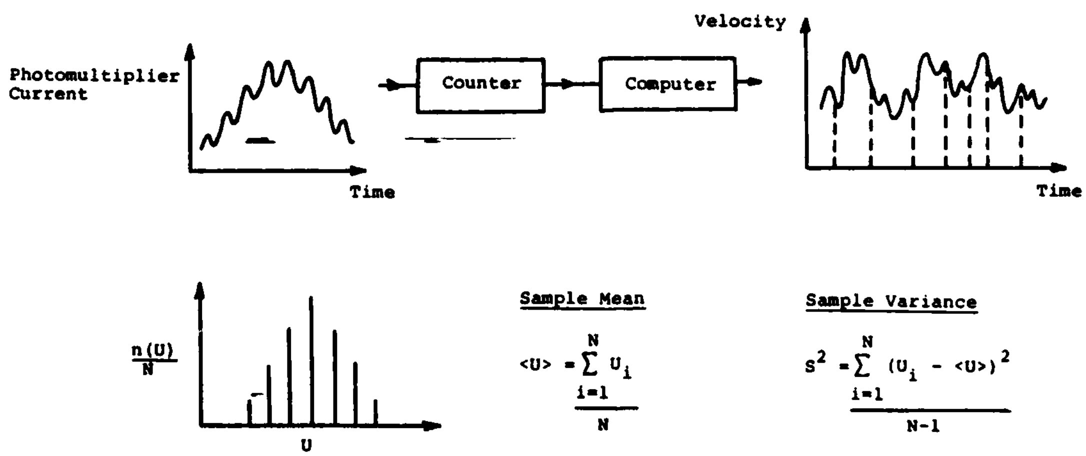


Figure 27. LDA off-axis backscatter configuration.

portion scattered into the solid angle subtended by the collecting lens is brought to focus on an aperture in front of a photomultiplier tube. The scattered light is modulated by the fringe pattern in the LDA probe volume and this, in turn, modulates the photomultiplier current. Since the fringe spacing is known from the laser wavelength and the intersection angle, θ, defined in Figure 27, determining the period, τ, or frequency, f, of the modulated photomultiplier current permits the determination of the particle velocity component normal to the fringe pattern, as shown in the equation below.

$$U = d/\tau = \frac{f\lambda}{2 \sin(\theta/2)}$$

The incoming doppler signal from the photomultiplier appears as in Figure 28. This signal is characteristic of the photomultiplier current being modulated by the light scattered from a single particle. This signal is input to a counter, where it excites a Schmitt trigger circuit whose square wave output is counted for eight cycles. An internal, very-high-frequency clock is gated for the duration of these eight cycles, and the counter registers the number of cycles of the clock that occur during this interval. This "number of clock counts" is the basic output of the LDA period counter. The number of clock counts for each of 1000 particles is stored by a digital computer, a velocity histogram is constructed, and the sample mean and sample variance are calculated, from which the mean velocity and turbulent intensity are deduced.



Sample Mean

$$\langle U \rangle = \frac{\sum_{i=1}^{N} U_i}{N}$$

Sample Variance

$$S^2 = \frac{\sum_{i=1}^{N} (U_i - \langle U \rangle)^2}{N-1}$$

Turbulent Intensity = $S/\langle U \rangle$

TE80-516

Figure 28. LDA counter schematic.

The preceding techniques yield the velocity component normal to the fringe pattern in the LDA probe volume. Obtaining other velocity components in the plane of the original fringe pattern involves rotation of the beam splitter about its axis, which realigns the fringe pattern.

The growing experience with this LDA system at DDA made the inlet turbulence measurement task a low-risk item in the hostile environment of the ACF.

3.3 ANNULAR CASCADE

3.3.1 Facility Description

The annular cascade portion of the contract was performed in the DDA small turbine research facility. This facility is designed to accommodate axial-flow and radial-inflow turbine rigs for aerodynamic testing. Cold-flow performance data may be obtained from single- or multi-stage turbines. In addition, the facility can be used as a full annular cascade rig to allow detailed testing of turbine stators, as it was for this contract. Scaled turbine stator and rotor models can be evaluated in this facility, which thus provides a means for obtaining data at greatly reduced hardware and test costs, and in less time than would be required for the procurement and test of a full-scale model.

Air, which is supplied to the facility through a 5-micron filter, passes through a series of indirect-fired burners and then through an ASME-standard, square-edged orifice for flow measurement before it enters a plenum that contains a turbine test rig. Exhaust air from the rig flows through two back pressure control valves into a silencer/exhaust stack, which can be evacuated with a steam ejector to a vacuum range of 20-26 in. Hg below ambient.

A control room contains the control systems and instruments necessary to operate the facility. Most of the data acquisition electronic equipment is also located in the control room. The control systems provide for independent variations of inlet air temperature, pressure, airflow, exhaust pressure, and mechanical speed of the rig. Therefore, equivalent airflows, expansion ratios, and Reynolds number can be controlled to simulate actual engine aerodynamic design conditions. Detailed specifications of the facility flow system are listed in Table 5.

TABLE 5. SMALL TURBINE FACILITY SPECIFICATIONS

Model size	Up to 9-in. diameter turbine rotors Up to 15-in. diameter annular vane cascade
Dynamometer	600 hp absorption, 570 hp drive (max)
Reduction gear	10:1
Maximum speed	35,000 rpm
Air supply	10 lb/sec @ 100 psia (max)
Inlet temperature	1000°F (max)
Turbine expansion ratio	7.5:1 (max)
Steam ejectors	Exhaust pressure: 10 in. Hg absolute
Secondary cooling	4 individually controlled supply lines (maximum cooling flow 0.75 lb/sec each)

Complete instrumentation capabilities are available as part of the small turbine facility. Heavily instrumented turbine rigs and vane assemblies are routinely tested as part of the turbine aerodynamic development programs. The following are typical of the test section measurements:

- o Total-static steady-state pressures
- o Steady-state temperatures
- o Vane and rotor exit angles
- o Vane and rotor exit (radial-circumferential) surveys
- o High-response pressure data
- o Blade running clearance with optical proximity probe
- o Hot film/wire anemometry data
- o Secondary cooling flows

Table 6 contains a detailed breakdown of the facility instrumentation and data acquisition capabilities. The on-line data acquisition system comprises modern, electronic, automated equipment for data retrieval, reduction, and printout.

TABLE 6. SMALL TURBINE FACILITY INSTRUMENTATION

Pressure scanner	Scanivalve system with 120 trapping ports
Pressure transducers	Druck, with 0-25 psia to 0-100 psia
Accuracy	$\pm$ 0.05% BSL
Thermocouple channels	48 Cr-Al, with provisions for additional channels
Accuracy	$\pm$ 0.5°F with calibration
Traversing gear	Radial-circumferential traversing mounts with computer interfaces
Anemometers	Single- and dual-sensor hot wire and hot film anemometry
Survey probes	Traversing Cr-Al thermocouple probes Traversing Cobra probes
Electrical measurements	HP 2302 subsystem 2911A crossbar switch (200 channels) 2402A digital voltmeter
Data acquisition	HP Digital Computer System HP 2100A with 32K word memory HP 2640A CRT display HP 2767A line printer Direct instrument interfaces

3.3.2 Cascade Description

All inlet and exit instrumentation for the annular cascade tests was located within the cascade itself. No general facility instrumentation was utilized in forming the data base.

The full annular cascade used in this test series was a modification of an existing 20-vane, IGT 505 Phase III inlet guide vane set. The coordinates for the 3-D vane are given in Appendix A. A full annular water cooling ring was added to the outer ring to provide the necessary cooling required to develop a temperature gradient large enough to employ the heat transfer measurement technique described in Section 3.1. Similarly, a 90-degree sector of the hub was provided with water cooling. Figures 29 and 30 show the inlet and exit views of the annular cascade. The cascade hub diameter was 7.840 inches and the tip diameter was 9.196 inches.

Cascade instrumentation included three inlet total temperature rakes and three inlet total pressure probes. In addition, three hub and three tip static pressure taps were installed. All inlet instrumentation was located in the same axial plane and was 0.240 inch (~0.3 axial chords) upstream of the vane leading edge. The angular location and radial depth of the inlet instrumentation is given in Table 7. Static pressure taps 1-6 are in the inlet plane. The remaining static pressure taps are located in the exit plane, which is approximately 1.17 inches (~0.7 axial chords) downstream of the vane trailing edge.

The cascade is also instrumented to make exit aerodynamic loss measurements. A two-dimensional traverse system provides the capability of circumferential and radial traverse in order to completely traverse the exit flow field. For this series of tests a miniature cobra probe, shown in Figure 31, was used to make the exit measurements. The precision and small size of this probe have resulted in a calibration and reduced blockage that have greatly improved the speed and accuracy with which 2-D loss profile maps can be obtained. The probe is fabricated from 0.032-in. diameter tubing, and is designed to pass through a 1/4-in. diameter instrumentation port.

The exit probe was located so that the probe tip was 1.21 inches downstream of the vane trailing edge. Circumferentially, the probe was centered at 0°; i.e., top dead center.

3.3.3 Endwall Heat Transfer Instrumentation

Since the primary purpose of the annular cascade was to study the effects of radial pressure gradients on the endwall heat transfer, it was necessary to instrument both the hub and tip endwalls. Both endwalls were 0.50 inch thick, with the hub wall fabricated from Type 410 Stainless Steel, while the tip endwall was fabricated from Type 304 Stainless Steel. These combinations of material thickness and thermal conductivity provided temperature differences through the wall that were large enough to minimize thermometry errors. Temperature differences through the hub endwall ranged from 60° to 160°F, while differences through the tip endwall were 100° to 190°F. This design ensured that a minimum error would result from the heat transfer measurement technique described in Section 3.1.

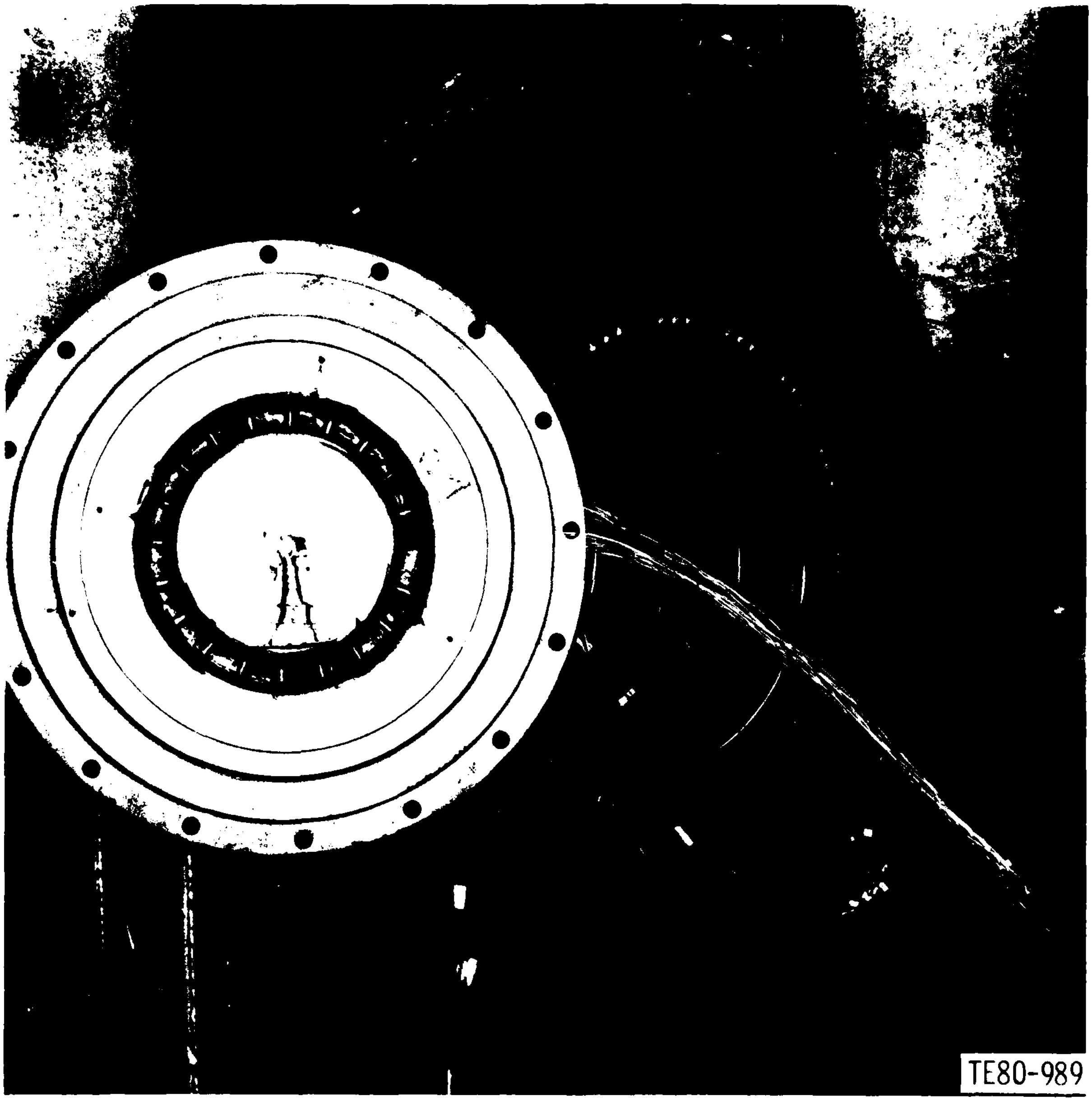


Figure 29. Inlet view of annular cascade.

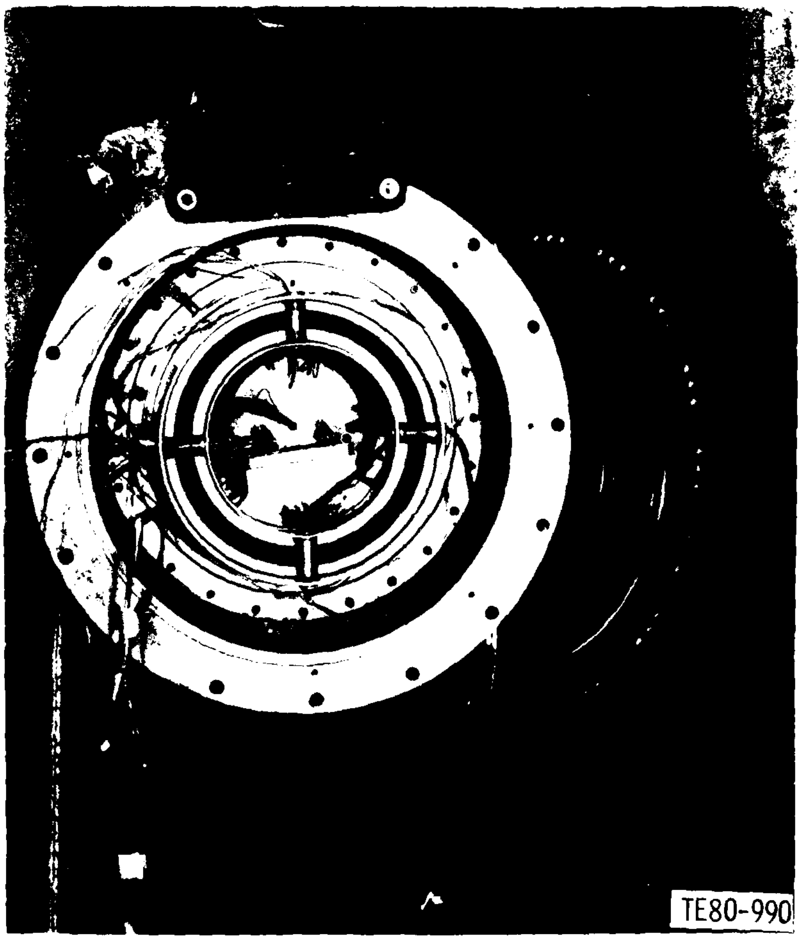


Figure 30. Exit view of annular cascade.

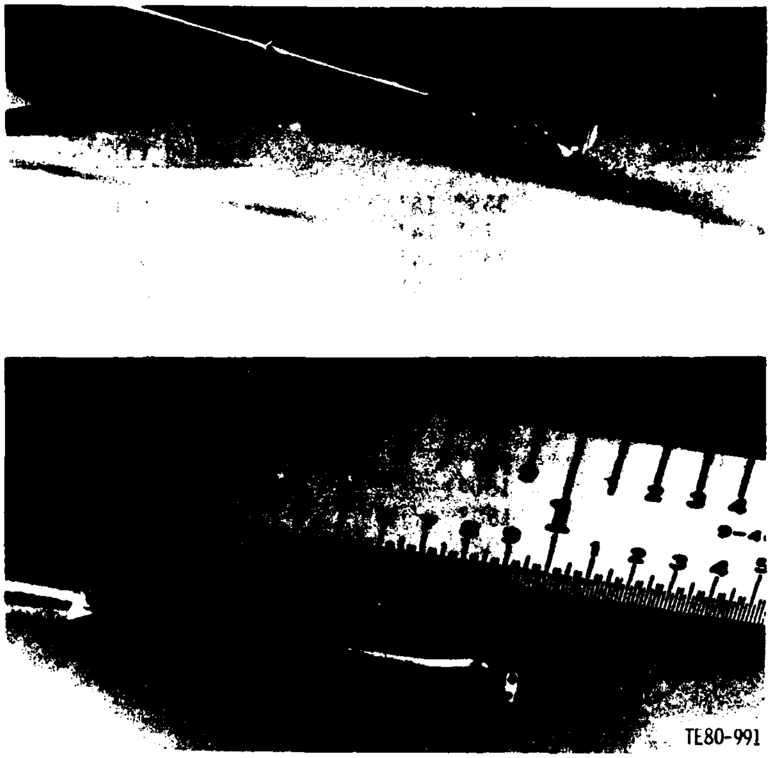


Figure 31. Miniature Cobra probe.

TABLE 7. ANNULAR CASCADE INLET AND EXIT INSTRUMENTATION LOCATION

Total Temperature Rakes (Inlet)

Rake No.	TC No.	Angle*	Radius (inches)**
1	1	21° 14'	4.490
	2	21° 14'	4.271
	3	21° 14'	4.040
2	4	111° 14'	4.490
	5	111° 14'	4.271
	6	111° 14'	4.040
3	7	273° 14'	4.490
	8	273° 14'	4.271
	9	273° 14'	4.040

Total Pressure Rakes (Inlet)

Total pressure probe No.	Angle*	Radius (inches)**
1	3° 14'	4.040
2	93° 14'	4.270
3	255° 14'	4.490

TABLE 7. (CONT)

Static Pressures (1-6 Inlet, 7-16 Exit)

Tap No.	Angle*	Radius (inches)**
1	345° 14'	Hub
2	75° 14'	Hub
3	237° 14'	Hub
4	345° 14'	Tip
5	75° 14'	Tip
6	237° 14'	Tip
7	324°	Hub
8	324°	Tip
9	252°	Hub
10	252°	Tip
11	180°	Hub
12	180°	Tip
13	108°	Hub
14	108°	Tip
15	36°	Hub
16	36°	Tip

*Measured clockwise from top dead center when looking upstream
**Hub radius = 3.920, tip radius = 4.598

The hub endwall measurements were made in the passage between vanes 10 and 11. The stacking axis of vane 10 is located at a circumferential angle of 166° 30', with the vane 11 stacking axis at an angle of 184° 30'. All angle measurements on the cascade are measured clockwise from top dead center when looking upstream. The axial location of instrumentation in the passage is referenced to a plane in the cascade inlet which is located 1.377 inches upstream from the vane stacking axis.

The thermocouple patterns for the hub endwall hot side and cooled side are shown in Figures 32 and 33, respectively. Because of the smaller size of the passage, it was not possible to obtain the quantity of measurements that were recorded in the linear cascade. The annular cascade hub hot side passage was instrumented with 42 thermocouples and the cold side contained 26 thermocouples. The locations of the hub hot side and cooled side thermocouples are given in Tables 8 and 9, respectively.

Thermocouple patterns very similar to those on the hub were installed on the tip endwall. Figures 34 and 35, respectively, show the tip endwall hot side and cooled side thermocouple patterns. Actual locations of the tip endwall thermocouples are given in Tables 10 and 11.

As in the linear cascade, special provisions were made to thermally isolate the passages where the heat transfer measurements were made from the vanes. In the annular cascade, this was accomplished by providing an 0.100-inch thick section of low thermal conductivity material between the endwall and the vane tip.

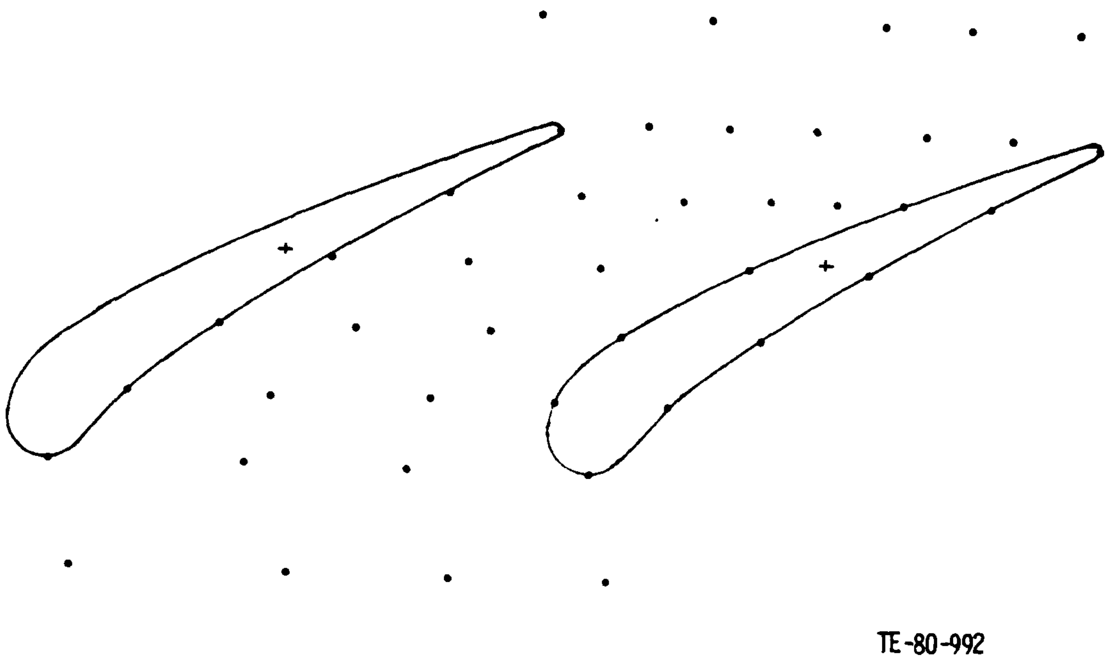


Figure 32. Relative thermocouple locations for hot gas side of hub endwall.

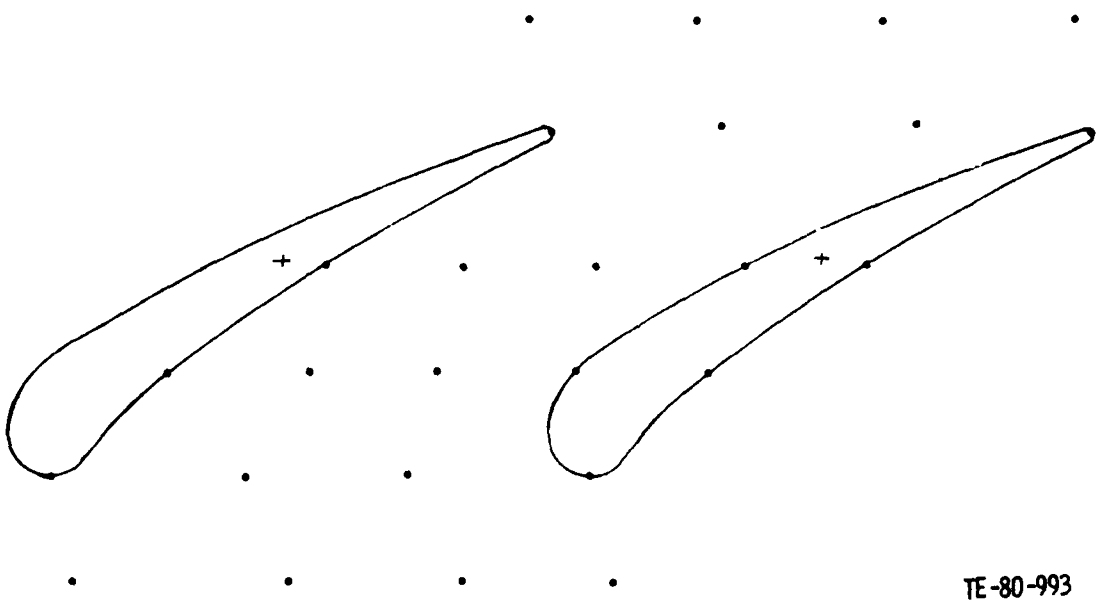


Figure 33. Relative thermocouple locations for cooled side of hub endwall.

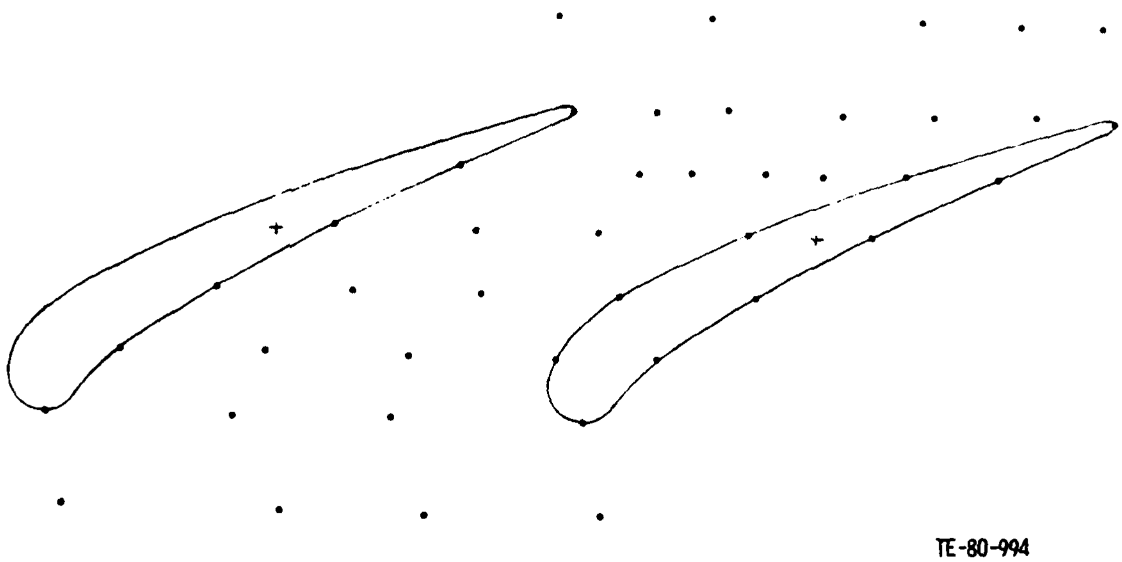


Figure 34. Relative thermocouple locations for hot gas side of tip endwall.

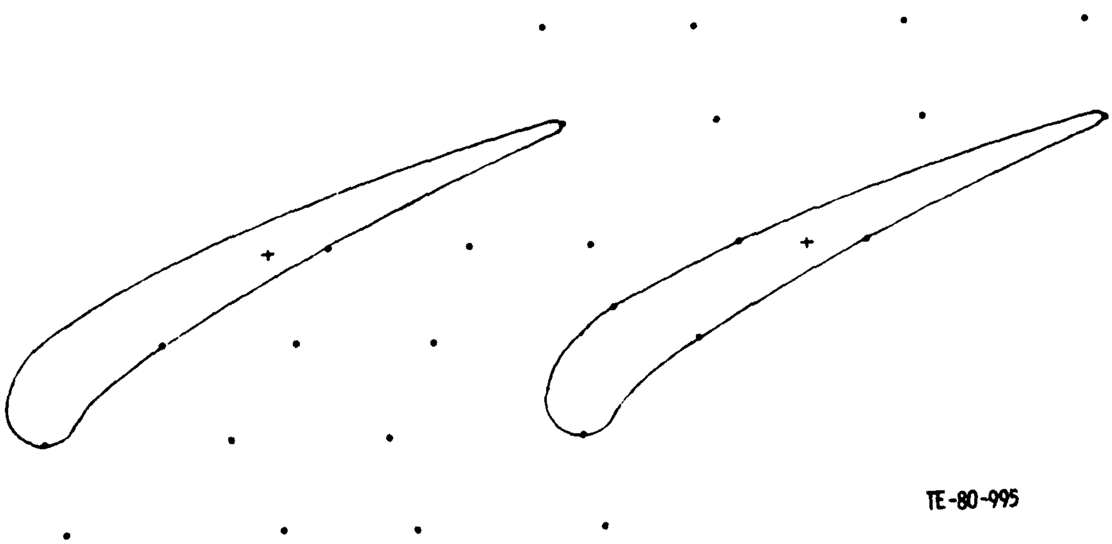


Figure 35. Relative thermocouple locations for cooled side of tip endwall.

TABLE 8. HUB HOT SIDE THERMOCOUPLE LOCATIONS

Axial distance from inlet reference plane (inches)	Angle*	Axial distance from inlet reference plane (inches)	Angle*
0.620	173° 27'	1.359	178° 21'
0.620	178° 44'	1.359	182° 56'
0.620	184° 10'	1.522	160° 59'
0.620	191° 27'	1.522	163° 54'
0.870	174° 3'	1.522	166° 6'
0.870	180° 11'	1.522	168° 21'
0.870	185° 40'	1.522	171° 15'
0.870	192° 5'	1.522	174° 44'
1.033	171° 29'	1.522	178° 59'
1.033	175° 15'	1.685	157° 22'
1.033	179° 28'	1.670	160° 15'
1.033	184° 50'	1.670	163° 11'
1.033	189° 29'	1.670	166° 49'
1.196	168° 29'	1.670	169° 43'
1.196	173° 6'	1.670	172° 27'
1.196	177° 34'	1.685	175° 22'
1.196	182° 3'	1.935	158° 5'
1.196	186° 35'	1.935	161° 43'
1.359	164° 56'	1.935	164° 37'
1.359	169° 1'	1.935	170° 26'
1.359	173° 53'	1.935	176° 5'

*Measured clockwise from top dead center when looking upstream.

TABLE 9. HUB COLD SIDE THERMOCOUPLE LOCATIONS

Axial distance from inlet reference plane (inches)	Angle*	Axial distance from inlet reference plane (inches)	Angle*
1.935	158° 5'	1.114	170° 7'
1.935	164° 14'	1.114	174° 34'
1.935	170° 26'	1.114	179° 11'
1.935	176° 5'	1.114	183° 30'
1.685	157° 22'	1.114	188° 7'
1.685	163° 11'	0.870	174° 3'
1.685	169° 43'	0.870	180° 11'
1.685	175° 22'	0.870	185° 40'
1.359	164° 56'	0.870	192° 5'
1.359	169° 1'	0.620	173° 27'
1.359	173° 53'	0.620	178° 44'
1.359	178° 20'	0.620	184° 10'
1.359	182° 56'	0.620	191° 27'

*Measured clockwise from top dead center when looking upstream.

TABLE 10. TIP HOT SIDE THERMOCOUPLE LOCATIONS

Axial distance from inlet reference plane (inches)	Angle*	Axial distance from inlet reference plane (inches)	Angle*
0.620	281° 35'	1.380	285° 52'
0.620	287° 25'	1.380	290° 37'
0.620	292° 17'	1.550	268° 27'
0.620	299° 37'	1.550	271° 34'
0.870	282° 12'	1.550	274° 20'
0.870	288° 39'	1.550	276° 17'
0.870	293° 58'	1.550	278° 46'
0.870	300° 12'	1.550	280° 31'
1.040	279° 44'	1.550	286° 27'
1.040	283° 11'	1.705	264° 34'
1.040	288° 2'	1.720	267° 18'
1.040	292° 52'	1.720	270° 37'
1.040	297° 44'	1.720	273° 46'
1.210	276° 30'	1.720	277° 30'
1.210	281° 4'	1.720	279° 58'
1.210	285° 37'	1.705	282° 38'
1.210	290° 1'	1.970	265° 10'
1.210	294° 30'	1.970	267° 54'
1.380	272° 37'	1.970	271° 9'
1.380	276° 46'	1.970	278° 9'
1.380	281° 48'	1.970	283° 14'

*Measured clockwise from top dead center when looking upstream.

TABLE 11. TIP COLD SIDE THERMOCOUPLE LOCATIONS

Axial distance from inlet reference plane (inches)	Angle*	Axial distance from inlet reference plane (inches)	Angle*
1.970	265° 10'	1.210	281° 4'
1.970	271° 9'	1.125	278° 12'
1.970	278° 9'	1.125	287° 9'
1.970	283° 14'	1.125	291° 42'
1.705	264° 34'	1.125	296° 12'
1.720	270° 37'	0.870	282° 12'
1.720	277° 30'	0.870	288° 39'
1.705	282° 38'	0.870	293° 58'
1.380	272° 37'	0.870	300° 12'
1.380	276° 46'	0.620	281° 35'
1.380	281° 48'	0.620	287° 43'
1.380	285° 52'	0.620	292° 17'
1.380	290° 37'	0.620	299° 37'

*Measured clockwise from top dead center when looking upstream.

4.0 SUMMARY OF TEST CONDITIONS

The contract originally consisted of two phases, with Phase I including non-film cooled tests in both the linear and annular cascades. Phase II testing was to consist of additional runs in the linear cascade with endwall film cooling added. Midway through the contract, the test program was modified at the request of the supporting agencies. The Phase II film-cooled tests were eliminated, along with the requirement for intrapassage hot-wire measurements. In place of these tests, the linear cascade was modified to make endwall adiabatic temperature measurements in the passage. Selected runs were repeated to gain the adiabatic temperature data. In addition, Phase II changes required data to be taken with a distorted inlet pressure profile and with a combined distorted temperature and pressure profile. For reporting purposes, the distorted inlet temperature profile data from Phase I will be included with the data of Phase II. A summary of the test conditions for the linear and annular cascades is presented in the next two sections.

4.1 LINEAR CASCADE TEST CONDITIONS

The test plan for the Phase I linear cascade investigation was organized to span the principal factors expected to influence vane endwall heat transfer and associated passage aerodynamics, except for the radial pressure gradient effects to be covered in the Phase I annular cascade task. Seven series of tests were conducted, as shown in Table 12.

TABLE 12. PHASE I LINEAR CASCADE DATA MATRIX

- o Cold baseline aero
- o Baseline heat transfer and hot aero
- o Reynolds number variation
- o Inlet turbulence level (gas temperature) variation
- o Tripped inlet boundary layer
  - o Cold baseline aero
  - o Heat transfer and hot aero
- o T_w/T_g variation (heat transfer only)
- o Inlet turbulence measurements

4.1.1 <u>"Cold Flow" Baseline Aerodynamics</u>

The inlet and exit aerodynamic data of the cascade was acquired at nominal exit Mach numbers of 0.3, 0.7, and 1.1, for a flow with an inlet total temperature of about 200°F. This series of runs was accomplished with the burner inoperative, so that the aerodynamic data is characteristic of low inlet turbulence conditions. The purpose of this test was to provide baseline loss data for use in comparisons with other effects present. All baseline data, both hot and cold, was taken with the facility exhaust valve removed, in order to acquire the baseline data at as low an exit Reynolds number as could be achieved in the facility. This resulted in the exit Reynolds number varying with exit Mach number. This relationship for the cold baseline aero runs is shown in Figure 36.

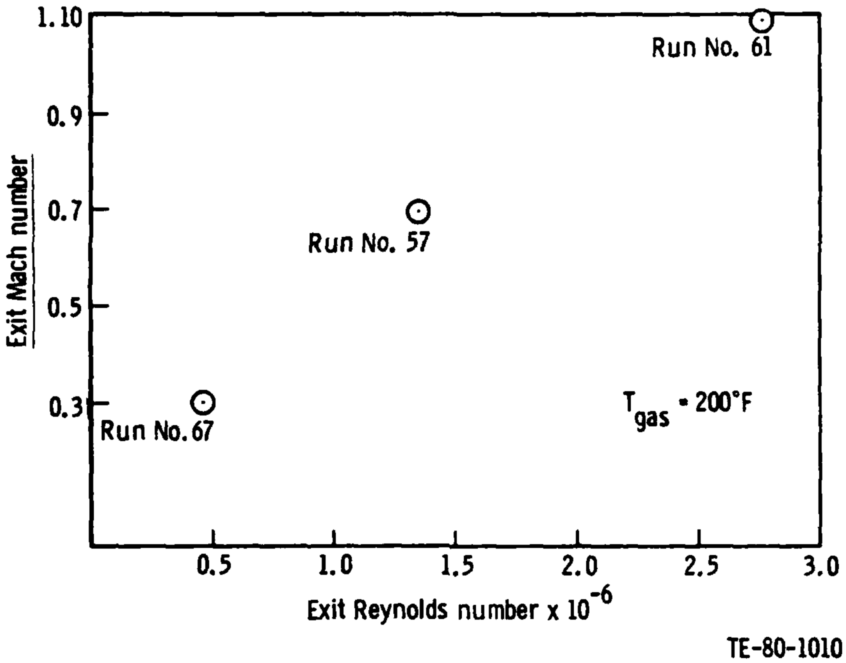


Figure 36. "Cold" baseline aero run conditions.

4.1.2 Baseline Heat Transfer and Hot Aerodynamics

This series of tests was intended to provide heat transfer and exit aero data at a nominal gas temperature of 800°F at the low Reynolds number condition to serve as a baseline. In other series of tests the exit Reynolds number was varied by increasing the facility back pressure. Thus the data in this series provides the baseline for determining the effects of the variables. Three runs were made in this series, at exit Mach numbers identical to those for the cold baseline aero runs. Exit Reynolds numbers were different due to the effect of gas temperature on the Reynolds number. Figure 37 shows the exit Mach and Reynolds numbers for the baseline heat transfer runs, as well as the Reynolds number variation runs. The 0.3 exit Mach number case provides heat transfer data from run 93C with the exit aero data contained in run 89, both runs being made at identical conditions. Similarly, at the 0.7 exit Mach number case the heat transfer data is from run 96 and the aero data is from run 86. At the 1.1 exit Mach number case, both heat transfer and aero data are avalable in run 91.

4.1.3 Reynolds Number Variation

To account for the effects of Reynolds number on heat transfer and aerodynamic performance, a set of runs was made at Reynolds numbers as divergent as facility limits would allow, by varying the facility pressure level with the exhaust control valve. This data was taken at an inlet gas temperature of 800°F for comparison with the baseline heat transfer and aero data. The exit Mach and Reynolds numbers for these runs are shown, along with those for the baseline data, in Figure 37. At the 0.3 exit Mach number condition it was possible

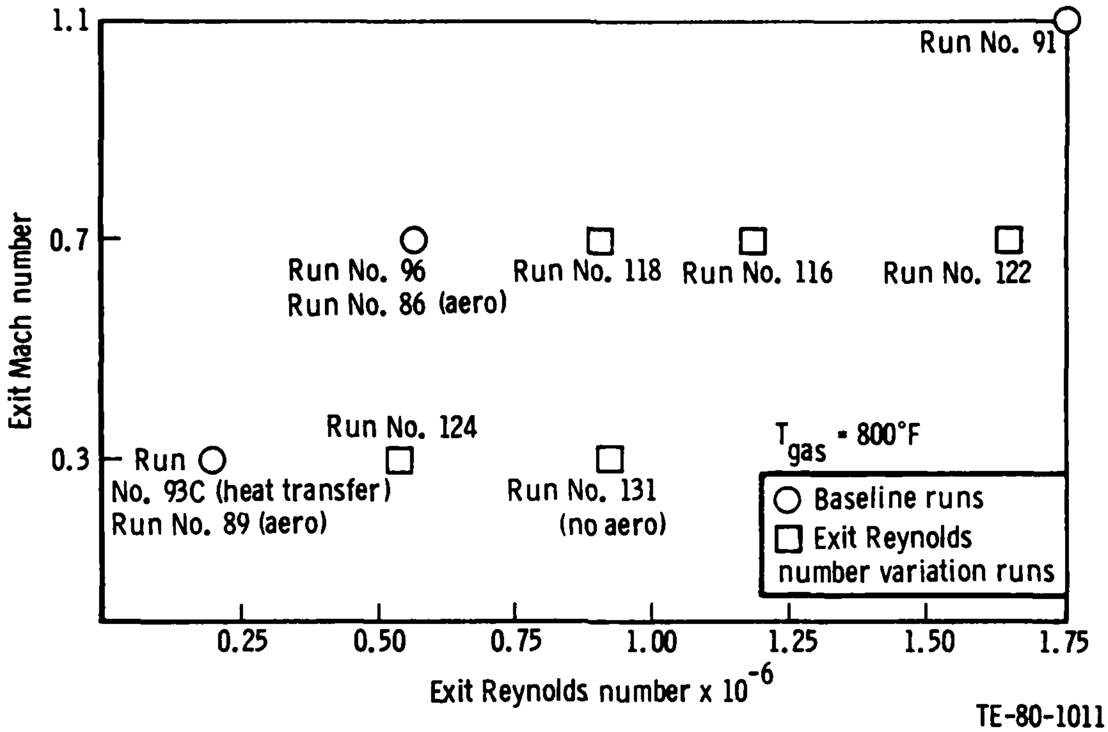


Figure 37. Run conditions for baseline and Reynolds number variation runs.

to get a 4.6:1 variation in exit Reynolds number between the baseline run 93C and the maximum Reynolds number run, number 131. No aero data was taken for run 131. An intermediate Reynolds number point, run 124, was taken and contains both heat transfer and aero data. This point is at nearly the same Reynolds number as the baseline 0.7 Mach number case, run 96. This provides data for examining Mach number effects at a constant Reynolds number.

At the 0.7 exit Mach number condition, a Reynolds number range of 2.9:1 was achieved. The high Reynolds number case, run 122, was at an exit Reynolds number of 1.66 x 10^6. This is quite close to the exit Reynolds number for the 1.1 exit Mach number baseline case, run 91, and should provide additional data on Mach number effects at a constant Reynolds number. This comparison is particularly important in this transonic region.

Two intermediate Reynolds number cases were also examined, runs 118 and 116. All three of the extended Reynolds number cases, runs 118, 116 and 122 contain both heat transfer and aerodynamic data. Run 118 was performed at an exit Reynolds number similar to the 0.3 Mach number, run 131. This provides an additional set of runs to examine Mach number effects. Due to the limitations in the facility air supply it was not possible to operate over a range of Reynolds numbers at the 1.1 exit Mach number level. However, this data matrix should be adequate to establish exit Mach number and Reynolds number effects over the range of interest to turbine designers.

4.1.4 Inlet Turbulence Level Variation

During a previous program conducted in the Aerothermodynamic Cascade Facility, it was shown that the turbulence level into the cascade was a function of the facility burner operating temperature. The previous data indicated a turbulence intensity of about 6 percent at 1000°F, and about 8 1/2 percent at 1500°F. The majority of the data taken in the linear cascade was at a gas temperature of 800°F. In order to provide data on the effects of turbulence levels on endwall heat transfer and cascade exit aerodynamic losses, a series of tests were run at temperatures from 600°F to 1000°F, as described in Figure 38. The baseline heat transfer and aero runs, numbers 93C, 96 and 91, were repeated at the 1000°F level, with only slight changes in the Reynolds numbers due to the gas temperature differences. This provides data for examining the effect of turbulence at the three different Mach number levels. A final point, run 95 (87 aero), was added to provide data over a wider range of gas temperature.

4.1.5 Tripped Inlet Boundary Layer

This series of tests was intended to provide data with inlet boundary layer conditions different from those that existed during the previous series of tests. The inlet boundary layer was altered for this series of tests by installing 3/8-inch diameter tubes on both endwalls upstream of the cascade. Their location was shown in Figure 5. These resulted in a significant change in the inlet velocity profile, as seen in Figure 39.

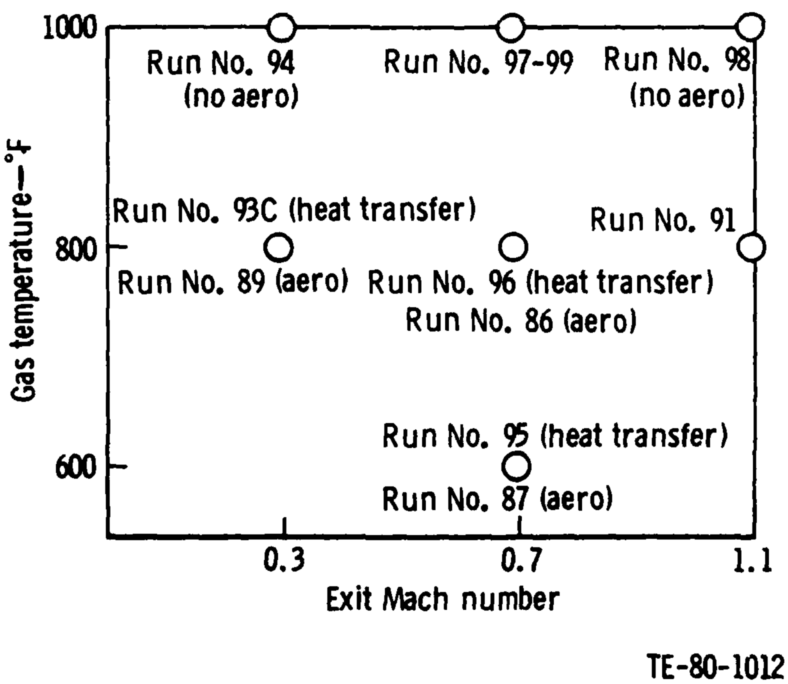


Figure 38. Run conditions for inlet turbulence cases.

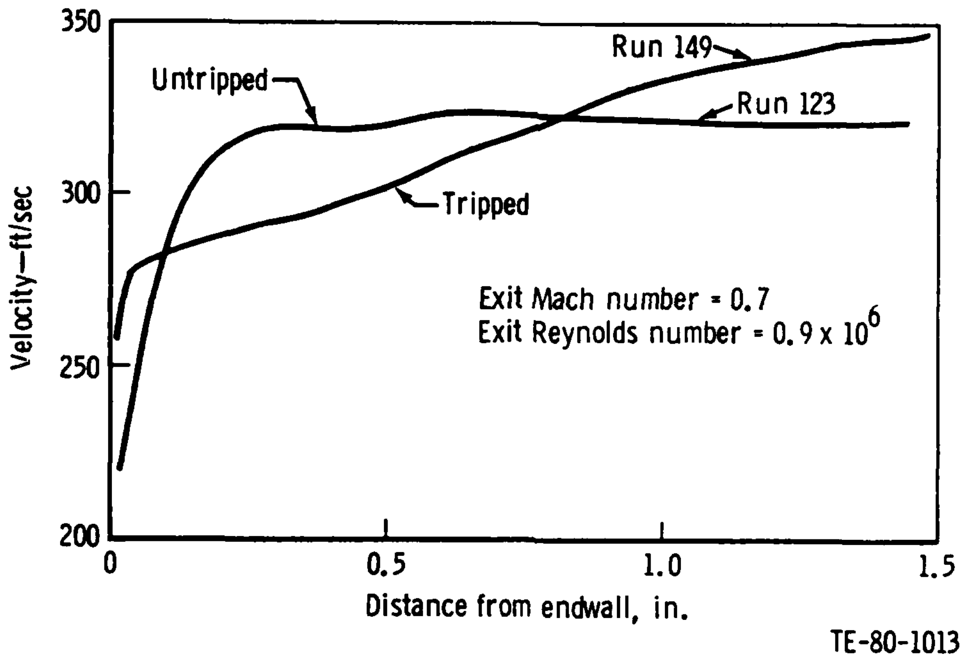


Figure 39. Effect of boundary layer trips on inlet velocity profile.

The tests in this series duplicated many of those in the previous series in order to adequately evaluate the effects of the change in the inlet profile. A series of runs, shown in Figure 40, was made at cold baseline conditions similar to those run previously, and shown in Figure 36. Similarly, heat transfer runs were made at conditions nearly identical to several of those in Figure 37. These run conditions are shown in Figure 41, and include two runs at gas temperatures other than 800°F. While not duplicating all the runs made with the normal inlet boundary layer, this series with the tripped inlet does provide several runs for comparison.

4.1.6 Wall-to-Gas Temperature Ratio Variation

A test series was conducted to provide data for the effect of wall-to-gas temperature ratio in the range of conditions encountered in engines, nominally 0.7 to 0.8. This was accomplished at a constant inlet total temperature condition, 800°F, to suppress effects associated with burner performance. Four values of wall-to-gas temperature ratio were included. The run conditions are shown in Figure 42.

4.1.7 Inlet Turbulence Measurements

A series of tests was performed to measure the turbulence intensity profile across the span of the cascade, using the LDA technique described in Section 3.2.7. Measurements were made at 1/2 inch spanwise intervals at a point midway between vanes 3 and 4 (as numbered in Figure 14) and 0.160 inch downstream of the vane leading edge plane. This is as far upstream as the measurement could be made due to the angle required to collect the laser beam. The turbulence results are in Vol. II, Section 4.

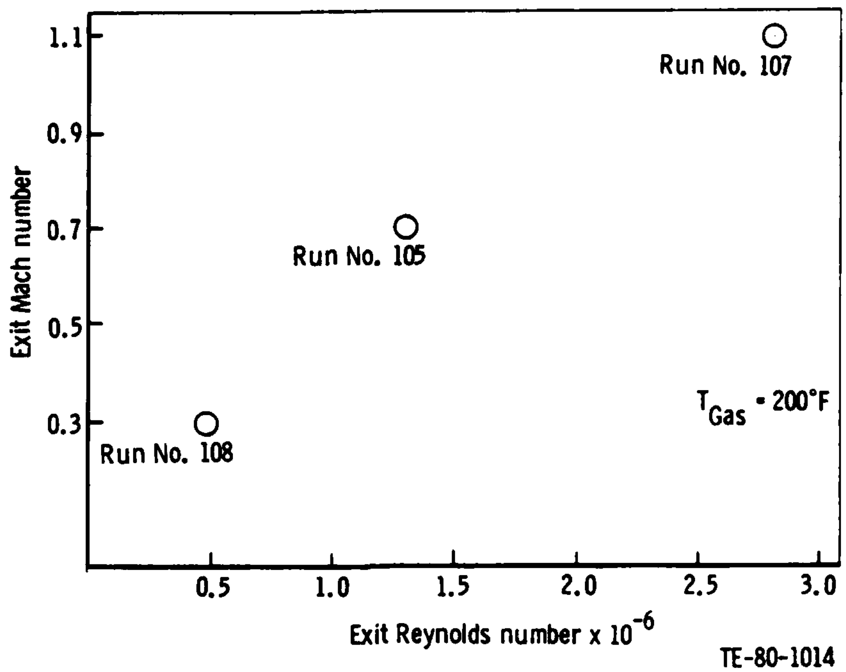


Figure 40. "Cold" aero run conditions for tripped inlet cases.

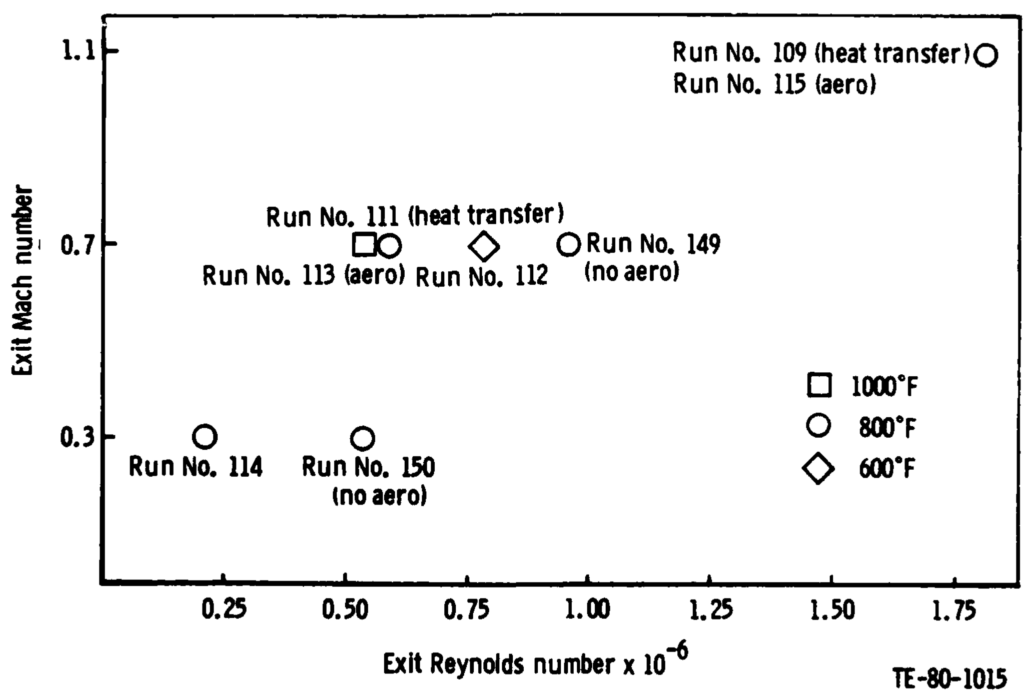


Figure 41. Run conditions for heat transfer runs with tripped inlet.

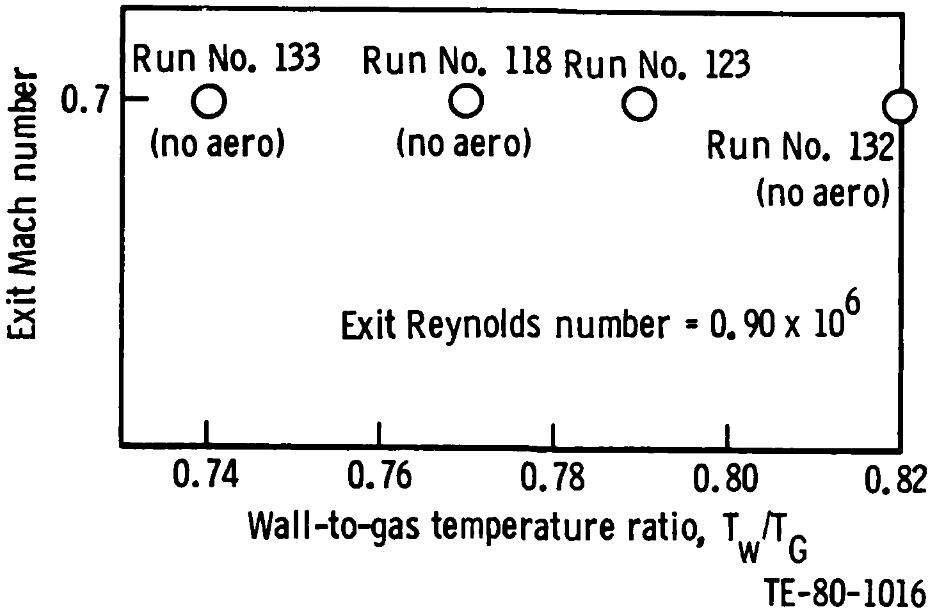


Figure 42. Run conditions for T_w/T_g variation cases.

Measurements were made at the conditions listed in Table 13. These were basically the conditions of selected baseline heat transfer runs. The three runs at an exit Mach number of 0.7 were intended to determine the effect of burner operating temperature on the turbulence intensity. The 0.3 exit case provides data at different inlet Mach number conditions. Whereas all 0.7 and 1.1 exit Mach number runs result in an inlet Mach number of approximately 0.22, the 0.3 exit Mach number condition results in an inlet Mach number of the order of 0.15. One final run was made with the burner inoperative to provide baseline turbulence intensity data for the facility.

This data completed the requirements for the Phase I data matrix.

TABLE 13. RUN CONDITIONS FOR LINEAR CASCADE INLET TURBULENCE MEASUREMENTS

	Inlet conditions				Exit conditions		
Run	Gas total temperature (°F)	Total pressure (psia)	Static pressure (psia)	Mach number	Mach number	Reynolds number x 10^{-6}	Expansion ratio
A	607	20.6	20.1	0.20	0.71	0.72	1.40
B	811	21.2	20.5	0.22	0.72	0.60	1.40
C	991	22.1	21.3	0.22	0.72	0.54	1.40
D	780	14.8	14.6	0.14	0.29	0.21	1.06
E	85	15.1	15.1	0.16	0.32	0.62	1.07

4.1.8 Phase II Test Matrix

As previously discussed, the Phase II test plan was revised during the contract. This revision provided for the data matrix shown in Table 14. It was planned to acquire data at three exit Mach numbers, 0.3, 0.7 and 1.1, for each of the three distorted inlet conditions. The distorted inlet temperature profile case was to be run with a uniform inlet pressure profile. However, since the temperature profile was generated by injecting coolant downstream along the wall through the boundary layer trip tubes (see Figure 5 for location), it was not possible to develop a distorted inlet temperature profile without simultaneously creating a distorted pressure profile. This provided data with a combined pressure and temperature distortion.

TABLE 14. PHASE II LINEAR CASCADE DATA MATRIX

- o Distorted inlet temperature profile from Phase I
- o Distorted inlet pressure profile
- o Combined distorted temperature and pressure profiles
- o Adiabatic endwall measurements

The distorted inlet pressure profile was achieved by injecting coolant upstream through the same tubes. This resulted in a significant distortion of the pressure profile while maintaining a uniform temperature profile at a reduced temperature level.

Thus, only two of the three desired inlet conditions could be achieved. Consequently, in addition to taking data at the three exit Mach number conditions, data was also taken at three different exit Reynolds numbers for both cases. The exit conditions for the data are shown in Figure 43. Runs 165-170 were with the combined distorted temperature and pressure profiles while runs 171-174 were with a distorted inlet pressure profile. No data is reported at the 0.3 exit Mach number condition with the distorted pressure profile. The very low operating pressure required to run this condition made it impossible to achieve a significant inlet pressure gradient.

The final item in the Phase II data matrix is the adiabatic endwall measurements. At the time the contract statement of work was modified, several baseline heat transfer tests had been completed. These tests were rerun after installation of the adiabatic endwall required by the contract changes. Consequently, adiabatic endwall temperature contours were recorded for all Phase I and Phase II tests with the exception of the three Phase I baseline cold aerodynamic runs.

Facility operating conditions for all linear cascade runs are given in Table 15. Inlet Mach numbers and Reynolds numbers for runs with distorted inlets are approximate due to the effects of the distorted pressure profiles. The Mach and Reynolds number are calculated, based on one element of the inlet core pressure rakes. In some cases with the distorted pressure profiles this element is not representative of the true inlet condition. These parameters should be recalculated based on the integrated values from all inlet rake elements.

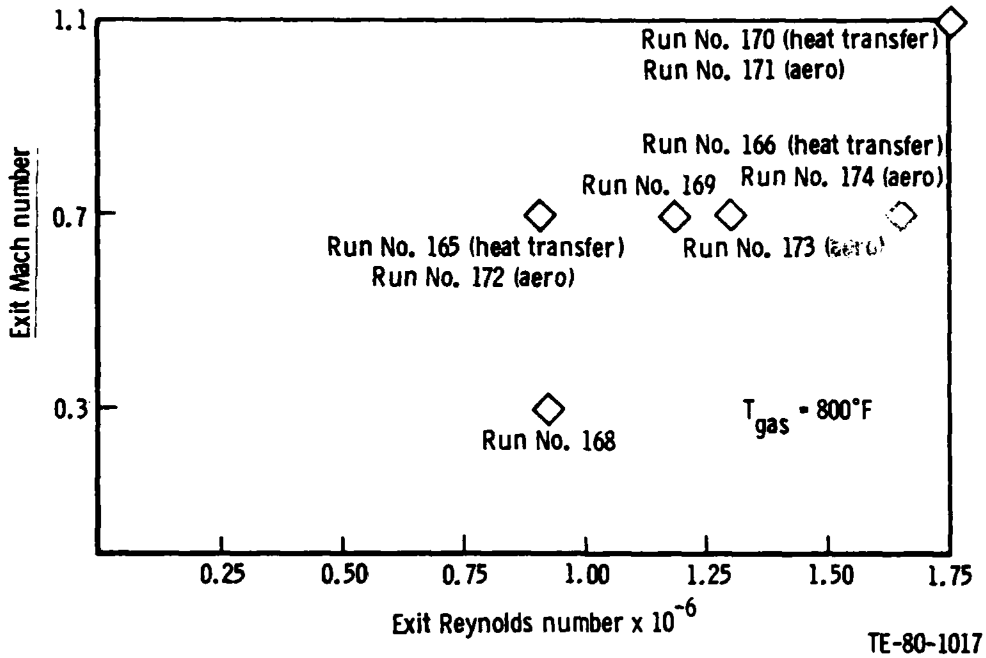


Figure 43. Run conditions for distorted inlet cases.

TABLE 15. LINEAR CASCADE RUN CONDITIONS

	Inlet conditions					Exit conditions		
Run No.	Gas total temperature (°F)	Total pressure (psia)	Static pressure (psia)	Mach number	Reynolds number x 10^{-6}	Mach number	Reynolds number x 10^{-6}	Expansion ratio
57	197	21.4	20.9	0.19	0.43	0.71	1.34	1.40
61	196	37.5	36.5	0.20	0.81	1.10	2.76	2.13
67	225	15.5	15.3	0.14	0.23	0.30	0.46	1.06
86	814	21.4	21.0	0.18	0.19	0.70	0.59	1.37
87	614	21.6	21.1	0.18	0.23	0.71	0.74	1.39
89	785	15.4	15.3	0.09	0.07	0.27	0.20	1.05
91	817	51.7	50.3	0.20	0.50	1.10	1.68	2.11
94	1078	15.5	15.4	0.10	0.06	0.28	0.17	1.05
98	1017	55.7	54.4	0.19	0.43	1.09	1.52	2.07
99	782	21.8	21.2	0.19	0.17	0.69	0.52	1.36
105	213	21.5	20.9	0.20	0.46	0.71	1.31	1.40
107	197	38.2	36.8	0.23	0.94	1.10	2.83	2.13
108	228	15.9	15.8	0.11	0.18	0.31	0.48	1.07
109	799	55.2	53.3	0.23	0.60	1.12	1.82	2.11
111	807	21.3	20.8	0.20	0.20	0.68	0.59	1.36
112	606	22.3	21.7	0.20	0.27	0.72	0.78	1.40
113	1000	22.4	21.8	0.21	0.19	0.72	0.54	1.40
114	776	15.5	15.4	0.10	0.08	0.28	0.21	1.05
116	815	43.4	42.3	0.19	0.40	0.70	1.20	1.37

TABLE 15. (CONT)

Run No.	Inlet conditions: Gas total temperature (°F)	Total pressure (psia)	Static pressure (psia)	Mach number	Reynolds number x 10^{-6}	Exit conditions: Mach number	Reynolds number x 10^{-6}	Expansion ratio
118	799	34.6	33.9	0.18	0.31	0.69	0.96	1.36
122	769	59.8	58.4	0.19	0.57	0.71	1.74	1.39
123	770	32.0	31.3	0.18	0.30	0.69	0.92	1.36
124	885	37.4	37.0	0.12	0.21	0.30	0.50	1.06
131	757	64.4	64.0	0.10	0.32	0.30	0.96	1.06
132	822	34.7	33.9	0.18	0.31	0.69	0.95	1.36
133	819	34.0	33.3	0.18	0.30	0.69	0.94	1.37
149	799	32.7	31.7	0.21	0.34	0.69	0.91	1.36
150	795	34.6	34.4	0.09	0.16	0.28	0.48	1.06
165	819	33.4*	33.0	0.14*	0.23*	0.70	0.92	1.38
166	818	59.2*	57.9	0.18*	0.52*	0.71	1.65	1.38
168	788	62.5*	62.2	0.08*	0.25*	0.30	0.91	1.06
169	822	45.0*	44.0	0.18*	0.39*	0.69	1.23	1.36
170	807	56.8*	54.9	0.22*	0.62*	1.06	1.85	2.01
171	787	56.4*	54.0	0.26*	0.71*	1.05	1.87	1.98
172	800	33.9*	32.8	0.21*	0.36*	0.70	0.96	1.38
173	787	45.2*	43.7	0.22*	0.50*	0.71	1.30	1.38
174	780	59.8*	57.9	0.22*	0.65*	0.69	1.69	1.36

*Distorted inlet runs require special handling of these values (see text).

4.2 ANNULAR CASCADE TEST CONDITIONS

The annular cascade was intended to supply data on the effects of the one important variable that cannot be simulated in the linear 2-D cascade; that is, the radial pressure gradient. Data from the annular cascade should be adequate to determine the effect of this variable on the secondary flow system and resulting endwall heat transfer.

As in the linear cascade, data was acquired at three exit Mach numbers, 0.4, 0.7 and 1.1, over a range of exit Reynolds numbers. Combinations of exit Mach numbers and Reynolds numbers at which data were taken are shown in Figure 44. Run conditions carrying two run numbers indicate that exit aerodynamic surveys, as well as hub and tip endwall heat transfer data, were taken. The second run number is that of the run containing the aero data, whereas the first number is the run containing the heat transfer data. Points with only one run number indicate that only heat transfer data were recorded. All runs in Figure 44 were made at an inlet gas temperature of 425°F.

Figure 44 shows that Reynolds number effects were investigated by a series of 5 runs containing both aero and heat transfer data. These data were taken at an exit Mach number of 0.7 and represent a 6:1 variation in Reynolds number. A similar series of runs was performed at an exit Mach number of 1.1. These runs, with the exception of one, contain only heat transfer data.

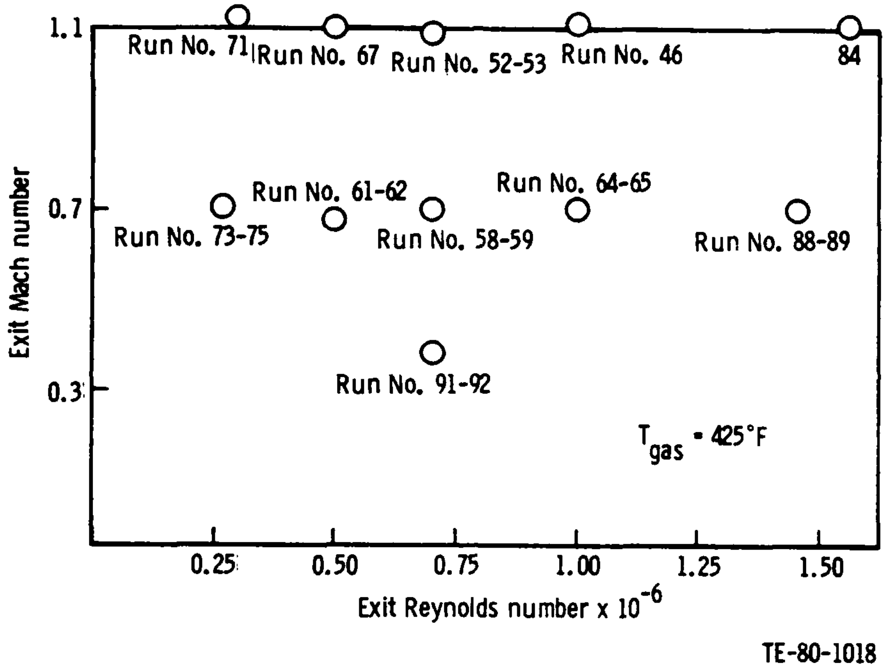


Figure 44. 425° annular cascade run conditions.

Mach number effects were examined by a series of runs at exit Mach numbers of 0.4, 0.7 and 1.1, all at an exit Reynolds number of 0.7×10^6. As shown in Figure 44, these runs all contain both heat transfer and exit aerodynamic data.

In addition to the runs shown in Figure 44, three additional heat transfer runs were made to provide data on the effects of wall-to-gas temperature ratio. Run 19 was made at 250°F, run 21 at 325°F, and run 77 at 512°F. All were run at an exit Mach number of 0.7 and an exit Reynolds number of 0.7×10^6. These three, combined with run 58, provide four sets of heat transfer data over a range of T_w/T_g from approximately 0.7 to 0.8.

Facility operating conditions for all annular cascade runs are given in Table 16.

TABLE 16. ANNULAR CASCADE RUN CONDITIONS

Run No.	Inlet conditions: Gas total temperature (°F)	Total pressure (psia)	Hub static pressure (psia)	Tip static pressure (psia)	Exit conditions: Mach number	Reynolds number x 10^6	Expansion ratio
19	251	30.2	29.2	29.3	0.70	0.71	1.38
21	324	33.7	32.7	32.8	0.70	0.70	1.39
46	425	47.6	46.0	46.1	1.11	1.01	2.14
52,53*	425	33.4	32.2	32.3	1.09	0.71	2.09
58,59*	424	38.9	37.7	37.8	0.70	0.70	1.38
61,62*	429	28.4	27.6	27.7	0.68	0.50	1.36
64,65*	422	55.8	54.2	54.4	0.70	1.01	1.39
67	429	23.9	23.0	23.1	1.10	0.50	2.14
71	425	13.7	13.2	13.2	1.12	0.29	2.17
73,75*	425	15.1	14.6	14.7	0.70	0.27	1.39
77	512	43.9	42.7	42.8	0.70	0.70	1.38
84	424	73.3	70.8	70.9	1.11	1.56	2.14
88,89*	424	81.1	78.7	78.9	0.70	1.46	1.38
91,92*	422	60.4	59.7	59.8	0.39	0.70	1.11

*Dual run numbers indicate combined aero and heat transfer runs with heat transfer data recorded under first number and aero data recorded under second number.

5.0 DATA ACQUISITION AND REDUCTION PROCEDURES

5.1 INTRODUCTION

The complete data set for endwall heat transfer runs consists of acquisition data and reduced data generated during testing and data reduced after testing. Heat transfer and aerodynamic data were taken for both the linear cascade and the annular cascade.

Appendix B contains an illustrative data set for one linear cascade run and one annular cascade run. The aerodynamic data set is slightly abridged, in that reduced data for only one span position is included out of full exit traverse data for nine span positions.

Due to the large volume of data associated with each of the 37 linear cascade runs and 14 annular cascade runs, a summarized data set for each run will be included in this report. All of the linear cascade raw and reduced data will be included in the computerized data base. For linear cascade runs, the complete summarized data set will include a summary sheet of run conditions and mixed-out conditions, endwall temperature and pressure contours, adiabatic endwall temperature contours, Stanton number contours, vane $V/V_{critical}$ plots, aerodynamic exit data summary plots, and inlet velocity and temperature profiles. For annular cascade runs, the summarized data set will include hub and tip endwall temperature and Stanton number contour plots as well as a summary of mass-averaged and mixed-out parameters as a function of radial position, and summary plots of local and mixed-out pressure loss coefficients and exit air angles.

The acquisition of data and reduction of data for one linear cascade run and one annular cascade run is discussed below.

5.2 LINEAR CASCADE DATA SET

The acquisition data set for the linear cascade begins with a page which summarizes the facility conditions for run 116. The summary sheet appears only once in Appendix B on page 90, but generally appears four or five times in an acquisition data set, as the facility conditions are periodically monitored. The summary sheet lists inlet total pressure, static pressure, total temperature, Mach number, $V/V_{critical}$, and Reynolds number based on true chord. The ideal exit conditions are based on measured exit static pressures and the isentropic flow assumption. The exit static pressure is the average of the thirteen statics in row 2 of the sidewall exit statics shown on page 102. The cascade flowrate is the calculated standard orifice flow-rate in lbm/sec upstream of the cascade. The summary sheet also gives the cascade expansion ratio, static pressure ratio, and input parameters for the finite element program Stanton number calculation.

5.2.1 Acquisition Data

In the discussion of data acquisition procedures, the term "reading" is often used. Each thermocouple "reading" is based on an average of ten readings of the digital voltmeter. Each pressure "reading" represents five readings of the digital voltmeter.

Heat transfer data for the linear cascade is acquired using a computer program which repeatedly reads a given set of thermocouples. For example, the program reads each of the heat transfer endwall thermocouples twice and averages the readings. It then prints the current average temperature (°F), the previous temperature (°F), rate of change of temperature, and coordinates of each thermocouple. The process is repeated until the readings stabilize, at which point the current temperatures are saved. The print for the last reading of the heat transfer endwall thermocouples for run 116 begins on page 91. The average wall temperature, gas temperature, and wall to gas temperature ratio are also given. The entire process is repeated for the vane thermocouples and finally the adiabatic endwall thermocouples. The print for the last vane and adiabatic thermocouple readings for run 116 is pages 94 through 99 of Appendix B, and has a format similar to that of the heat transfer endwall data.

The aerodynamic acquisition data for linear cascade runs begins with single span exit data on page 100 of the appendix. The single span traverse is a twenty-five-point midspan vertical traverse behind the fourth vane. The printed output gives the actual spanwise position, the setting angle and vertical position of the exit cone probe. For each vertical position, the tunnel inlet total pressure (PT), the exit probe total pressure (P1), the exit probe static pressure (P2-P5), and the exit total temperature (TT2) are printed.

Following the single span traverse data is a listing of sidewall static pressures, inlet core rake data and inlet boundary layer rake data. Each of the values represents a single reading of the thermocouple or pressure transducer. The sidewall statics are printed in rows by axial position. The inlet core rake data includes the spanwise position of each rake element (Y), temperature, pressure, Mach number, and velocity for the upper and lower core rake, respectively. The same information is given for the boundary layer rakes. Due to boundary layer rake instrumentation failures, a traversing inlet probe was added to the facility to obtain the boundary layer information. Data from the traversing probe is discussed below.

Vane static pressures are listed by spanwise position from the vane leading edge to the trailing edge on page 102. Endwall static pressures are listed by axial row from suction surface to pressure surface. As above, each of the static pressure values represents a single reading of the pressure transducer.

Inlet survey data taken with the traversing inlet probe begins on page 103. The first page of inlet data gives the reference inlet total pressure from one element of the inlet core rake (P_{ref}), the uncorrected probe pressure, and three readings of the probe thermocouple for each probe position (DWALL). The uncorrected pressures are corrected for tunnel unsteadiness based on the change in reference pressure with time. The time-corrected readings are then corrected for probe angle based on probe calibration. The three temperature readings are averaged. The final reduced inlet data for the traversing probe is shown on page 104.

The last item in the acquisition data set of pages 105 through 113, is the full exit traverse data taken behind vane 3. The full exit traverse data includes vertical traverse data taken at nine spanwise positions ranging from midspan to about 6% span. The print format for each span position is identical to the single span data print format described above. The rake and static pressure values following on pages 114 and 115 represent an average of seven readings.

5.2.2 Reduced Data

Data reduction for the heat transfer endwall of the linear cascade begins with curve fitting of the measured surface temperatures for the hot and cold surfaces. The curve fits are then used to obtain interpolated temperatures for the nodes of the finite element model. Page 116 of Appendix B shows the locations of the 53 thermocouples relative to the finite element grid of 338 nodes for the endwall hot surface.

The finite element method is used to solve the heat conduction equation, $\vec{\nabla}(K \vec{\nabla} T) = 0$, for the endwall in three dimensions. The surface heat flux is computed as $Q = K\vec{\nabla} T \cdot \vec{S}$, where $\vec{S}$ is the surface normal vector. Stanton numbers are then computed from $St = Q/\rho U_\infty Cp(T-T_\infty)$.

The finite element method involves the conversion of the differential equation and its boundary conditions into a single expression which is minimized with respect to all unknown temperatures. Error in the resulting solution is shared between the differential equation and the boundary conditions, in neither being completely satisfied.

In the three-dimensional endwall problem, a special boundary condition is present in that the endwall is insulated from the vane extensions by cement. Since the adiabatic boundary condition is not rigidly enforced by the finite element method, another analysis was run to validate the finite element method results. The verifying analysis used a finite difference technique, which rigidly enforced the adiabatic boundary condition, to solve the heat conduction equation. Several data sets were run, and the results from the two different analyses were found basically in agreement.

The finite element program can generate contour plots from node values of a given variable. Node temperatures for a model of the adiabatic endwall are obtained from thermocouple data using the same interpolation algorithm used for the heat transfer endwall.

The results of heat transfer data reduction are seen on pages 117 through 119. These pages are temperature and Stanton number contours for the heat transfer endwall. Page 119 shows a temperature contour plot for the adiabatic endwall.

Inlet pressure and temperature data were taken at thirty-six points from midspan to the heat transfer endwall (using the traversing probe described in Section 3.2.2, and as discussed in Section 5.2.1). The probe pressures are corrected for time variation in tunnel conditions and then corrected for probe angle based on probe calibration. Mach number and velocity are then computed from the corrected total pressure and average inlet static pressure. Reduced inlet data are shown on page 104 of Appendix B.

The 42 endwall static pressure values are used to generate pressure values for the 338 nodes of the endwall model, using an interpolation algorithm identical to that used for the thermocouples. The interpolated node pressures are used to generate a contour plot using the plotting routine from the finite element program.

Aerodynamic data for the full exit traverse and midspan exit traverse were taken with the five-port cone probe. At each probe position, the tunnel reference pressure was recorded to provide a correction for tunnel unsteadiness. Pages 120 and 121 show the raw probe data and the time-corrected and smoothed data for the midspan vertical traverse points of a full exit data set. The time-corrected and smoothed data are then used to determine local static pressure, Mach number, gas angles, and several loss parameters for each probe position. The reduced data for the midspan traverse of run 116 are shown on pages 122 through 125.

The local static pressure, Mach number and gas angles are determined from calibration curves for the cone probe. The parameters listed also include the exit gas angle BETA2, pressure loss coefficient based on ideal dynamic pressure OMEGA, and kinetic energy loss coefficient EBAR.

For each parameter listed, a final value, mass-averaged over one passage, is calculated for each span position. Mixed-out flow properties are also calculated for each span position. The method for calculating mixed-out properties assumes that a hypothetical uniform property state exists downstream of the cascade. It then solves conservation equations between cascade exit and mixed-out state for the unknown mixed-out parameters. The equations solved conserve energy, mass, axial momentum and tangential momentum, and require an iterative solution. One side of each equation is an integral, which may be evaluated from test data, and the other side contains only mixed-out variables. Page 126 of Appendix B lists mass-averaged and mixed-out properties for the midspan exit traverse of run 116.

The results of the aerodynamic data reduction begin on page 127 of Appendix B. The first page lists a summary of run inlet and exit conditions and a summary of mixed-out conditions. Page 128 shows inlet temperature and velocity profiles. Page 129 is a contour plot of endwall pressures, followed by a vane $V/V_{critical}$ plot on page 130. Page 131 shows plots of local exit Mach number, air angle, and pressure loss coefficient at the mid span position. The final page shows local pressure loss coefficient contours and (local B_2 - span average B_3) contours. Also given are summary plots of mixed-out pressure loss coefficient and air angle versus percent span.

The method used to calculate $V/V_{critical}$ values and loss coefficients is based on an upstream total pressure read from a single core rake element. For distorted inlet runs, the reading of a single core rake element does not provide a valid reference pressure for $V/V_{critical}$ and loss coefficient calculations. Thus, $V/V_{critical}$ plots and loss coefficient contours are not included for distorted inlet runs. Inlet profile data is provided and can be used to determine an effective inlet total pressure. Raw pressure data from the full exit traverse will be included in the data base, so the data needed to calculate pressure loss coefficients will be available in one form or another.

5.3 ANNULAR CASCADE DATA SET

Heat transfer and aerodynamic data for the annular cascade were taken in the small turbine research laboratory. The small turbine lab uses one data acquisition program with a fixed instrumentation set up for all tests. The summary of run conditions appears on page 133 of Appendix B. The print has been labeled to identify parameters of interest for the endwall contract tests.

Heat transfer and aerodynamic data sets for annular runs were given separate run numbers. The data set in Appendix B includes a summary of run conditions identified by a reading number (RDG 64) followed by heat transfer data labeled RUN 64. The aerodynamic data begins with another summary sheet labeled RDG 65, and the following exit survey data is labeled RDG 65.

5.3.1 Acquisition Data

The raw temperature data for heat transfer run 64 begins on page 134. Thermocouples 78 through 145 are located on the hub endwall. Thermocouples 78 through 123 are located on the hot surface of the endwall, and thermocouples 124 through 145 are located on the cold surface. As in the case of the linear cascade data, the thermocouples are read repeatedly until the readings stabilize. The final print for the hub thermocouple readings is included in Appendix B, and lists the temperatures that were saved as input for the finite element program.

Following the hub temperature data are the final tip endwall thermocouple readings. For the tip endwall, thermocouples 10 through 51 are located on the hot side, and thermocouples 52 through 77 are located on the cold side. Again, the data shown on pages 136 and 137 of Appendix B are the tip input for the finite element program.

The aerodynamic acquisition data for annular run (RDG) 65 begins on page 138 with a summary of run conditions which has the same format as page 133 of Appendix B. The summary is followed by exit survey data taken at ten radial or span positions. At each radial station, exit data is recorded for forty circumferential positions over one vane passage. Appendix B contains a listing of exit data for one radial station on page 138. At each circumferential position, the probe coordinates (θ, R) are printed, followed by inlet total pressure and the difference between inlet and exit total pressures. The difference in cobra probe side port pressures, an interpolated local static pressure (based on hub and tip values), and the exit air angle based on probe calibration are also listed.

5.3.2 Reduced Data

Data reduction for heat transfer data from the annular cascade was handled in the same manner as data from the linear cascade. Hub and tip endwalls were modeled separately, and interpolation was used to determine node temperature values for hot and cold surfaces of each endwall. Hub and tip finite element models are shown on pages 139 and 140. The finite element program was used to determine Stanton numbers for the nodes and to plot the resulting contours. Pages 141 through 144 are contour plots of hot surface temperature and Stanton number for hub and tip endwalls.

Data reduction for the annular aerodynamic data involves the calculation of several parameters based on exit survey data. Loss parameters calculated for an angular survey at the midspan radial position are shown on pages 145 and 146. The parameters listed include kinetic energy coefficient, KE COEF, and pressure loss coefficient based on ideal dynamic pressure, OMG ID, which compare with EBAR and OMEGA of linear cascade runs. Contour plots were generated for pressure loss coefficient and exit gas angle.

Exit properties for the annular cascade are mass-averaged for each span or radial position. Complete passage integrated flow properties are calculated, but they must be used with caution. The curve of each parameter vs % span does not extend to the endwalls, and the integration method used the constant measured value at the closest point to the endwall for all points between that spanwise point and the endwall.

Mixed-out flow properties are calculated for each span position, using a technique similar to that used for the linear cascade data. Conservation equations for mass, energy and momentum were solved for the mixed-out state properties.

The results of the annular cascade aerodynamic data reduction are shown on pages 147 through 149. Page 147 is a summary of exit mass-averaged and mixed-out data. Page 148 shows a contour plot of exit air angle and mixed-out air angle versus % span. Page 149 shows exit pressure loss coefficient contours and mixed-out pressure loss coefficient versus % span.

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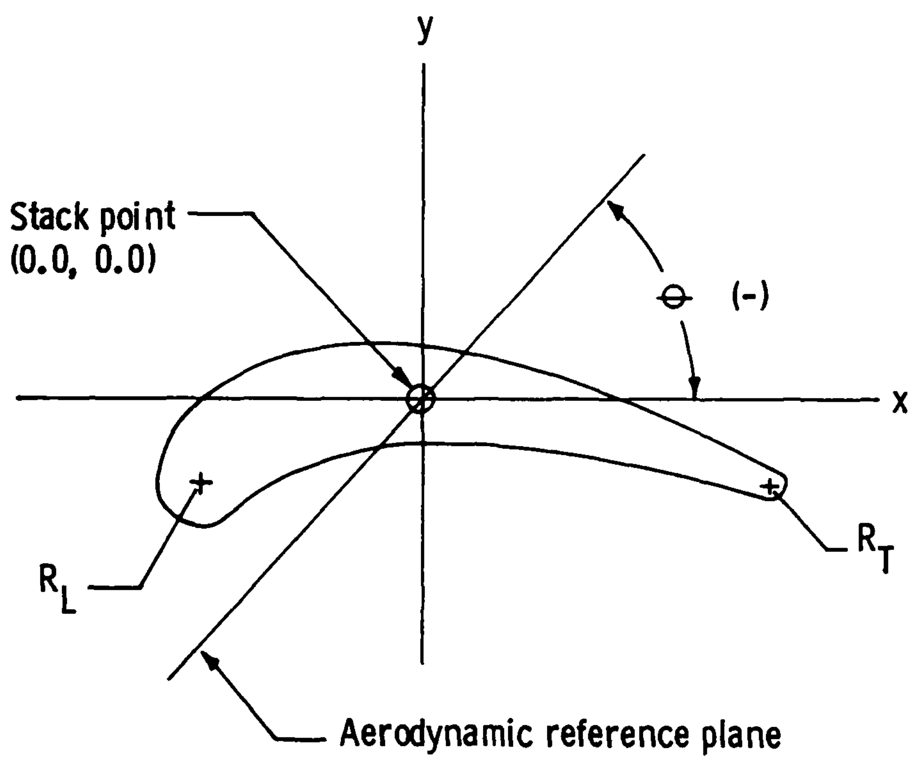
APPENDIX A

ANNULAR CASCADE VANE GEOMETRY

The accompanying data are turbine stator vane coordinates. The following sketch describes the stack point, the leading and trailing edge radii, and theta, the angle between the aerodynamic reference plane, and the x-axis.



R_L = radius at leading edge

R_T = radius at trailing edge

θ = angle between the aerodynamic reference plane and the x-axis

TE81-4591

Figure A-1. Stator vane coordinates.

TURBINE STATOR VANE COORDINATES TNC 11795 PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-58.5347	0.09543	0.01489	7.66600

STATION	X	Y	STATION	X	Y
1	-0.7523	-0.0807	31	0.6782	-0.0807
2	-0.7450	-0.0440	32	0.6626	-0.0956
3	-0.7292	-0.0150	33	0.6155	-0.0934
4	-0.6922	0.0232	34	0.5689	-0.0913
5	-0.6462	0.0499	35	0.5224	-0.0894
6	-0.5957	0.0667	36	0.4761	-0.0875
7	-0.5433	0.0762	37	0.4298	-0.0858
8	-0.4904	0.0809	38	0.3837	-0.0842
9	-0.4373	0.0827	39	0.3376	-0.0828
10	-0.3842	0.0828	40	0.2916	-0.0815
11	-0.3313	0.0817	41	0.2457	-0.0804
12	-0.2784	0.0795	42	0.1999	-0.0795
13	-0.2256	0.0764	43	0.1541	-0.0788
14	-0.1728	0.0725	44	0.1084	-0.0784
15	-0.1202	0.0678	45	0.0627	-0.0782
16	-0.0676	0.0625	46	0.0170	-0.0784
17	-0.0150	0.0567	47	-0.0286	-0.0789
18	0.0375	0.0503	48	-0.0743	-0.0798
19	0.0900	0.0434	49	-0.1199	-0.0811
20	0.1424	0.0361	50	-0.1655	-0.0830
21	0.1949	0.0283	51	-0.2110	-0.0854
22	0.2473	0.0200	52	-0.2566	-0.0886
23	0.2998	0.0112	53	-0.3021	-0.0925
24	0.3522	0.0019	54	-0.3476	-0.0974
25	0.4047	-0.0078	55	-0.3930	-0.1035
26	0.4572	-0.0182	56	-0.4381	-0.1111
27	0.5096	-0.0292	57	-0.4830	-0.1204
28	0.5621	-0.0408	58	-0.5275	-0.1321
29	0.6145	-0.0531	59	-0.5710	-0.1467
30	0.6670	-0.0663	60	-0.6134	-0.1656

TURBINE STATOR VANE COORDINATES   TNC 11795   PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-58.5347	0.09543	0.01489	7.74000

STATION	X	Y	STATION	X	Y
1	-0.7523	-0.0807	31	0.6782	-0.0807
2	-0.7450	-0.0440	32	0.6626	-0.0956
3	-0.7292	-0.0150	33	0.6155	-0.0934
4	-0.6922	0.0232	34	0.5689	-0.0913
5	-0.6462	0.0499	35	0.5224	-0.0894
6	-0.5957	0.0667	36	0.4761	-0.0875
7	-0.5433	0.0762	37	0.4298	-0.0858
8	-0.4904	0.0809	38	0.3837	-0.0842
9	-0.4373	0.0827	39	0.3376	-0.0828
10	-0.3842	0.0828	40	0.2916	-0.0815
11	-0.3313	0.0817	41	0.2457	-0.0804
12	-0.2784	0.0795	42	0.1999	-0.0795
13	-0.2256	0.0764	43	0.1541	-0.0788
14	-0.1728	0.0725	44	0.1084	-0.0784
15	-0.1202	0.0678	45	0.0627	-0.0782
16	-0.0676	0.0625	46	0.0170	-0.0784
17	-0.0150	0.0567	47	-0.0286	-0.0789
18	0.0375	0.0503	48	-0.0743	-0.0798
19	0.0900	0.0434	49	-0.1199	-0.0811
20	0.1424	0.0361	50	-0.1655	-0.0830
21	0.1949	0.0283	51	-0.2110	-0.0854
22	0.2473	0.0200	52	-0.2566	-0.0886
23	0.2998	0.0112	53	-0.3021	-0.0925
24	0.3522	0.0019	54	-0.3476	-0.0974
25	0.4047	-0.0078	55	-0.3930	-0.1035
26	0.4572	-0.0182	56	-0.4381	-0.1111
27	0.5096	-0.0292	57	-0.4830	-0.1204
28	0.5621	-0.0408	58	-0.5275	-0.1321
29	0.6145	-0.0531	59	-0.5710	-0.1467
30	0.6670	-0.0663	60	-0.6134	-0.1656

TURBINE STATOR VANE COORDINATES TNC 11795 PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-58.6718	0.09540	0.01490	7.98000

STATION	X	Y	STATION	X	Y
1	-0.7660	-0.0738	31	0.7006	-0.0738
2	-0.7584	-0.0367	32	0.6855	-0.0887
3	-0.7421	-0.0074	33	0.6372	-0.0873
4	-0.7037	0.0310	34	0.5893	-0.0859
5	-0.6560	0.0572	35	0.5416	-0.0845
6	-0.6039	0.0732	36	0.4939	-0.0833
7	-0.5501	0.0818	37	0.4464	-0.0820
8	-0.4959	0.0857	38	0.3990	-0.0809
9	-0.4416	0.0869	39	0.3516	-0.0798
10	-0.3873	0.0865	40	0.3044	-0.0788
11	-0.3331	0.0850	41	0.2572	-0.0780
12	-0.2790	0.0824	42	0.2101	-0.0772
13	-0.2250	0.0790	43	0.1631	-0.0766
14	-0.1710	0.0749	44	0.1160	-0.0762
15	-0.1171	0.0701	45	0.0691	-0.0760
16	-0.0633	0.0647	46	0.0221	-0.0760
17	-0.0095	0.0586	47	-0.0246	-0.0764
18	0.0443	0.0525	48	-0.0717	-0.0770
19	0.0960	0.0457	49	-0.1186	-0.0780
20	0.1517	0.0385	50	-0.1655	-0.0795
21	0.2054	0.0310	51	-0.2124	-0.0815
22	0.2592	0.0230	52	-0.2592	-0.0842
23	0.3129	0.0146	53	-0.3061	-0.0876
24	0.3667	0.0057	54	-0.3529	-0.0920
25	0.4204	-0.0036	55	-0.3996	-0.0976
26	0.4742	-0.0135	56	-0.4462	-0.1046
27	0.5280	-0.0239	57	-0.4925	-0.1135
28	0.5818	-0.0350	58	-0.5383	-0.1248
29	0.6356	-0.0468	59	-0.5832	-0.1394
30	0.6894	-0.0594	60	-0.6269	-0.1587

TURBINE STATOR VANE COORDINATES TNC 11795 PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-58.8728	0.09537	0.01494	8.29400

STATION	X	Y	STATION	X	Y
1	-0.7838	-0.0653	31	0.7260	-0.0653
2	-0.7761	-0.0277	32	0.7108	-0.0802
3	-0.7592	0.0020	33	0.6612	-0.0792
4	-0.7190	0.0407	34	0.6119	-0.0784
5	-0.6694	0.0664	35	0.5626	-0.0776
6	-0.6155	0.0815	36	0.5137	-0.0768
7	-0.5600	0.0891	37	0.4647	-0.0760
8	-0.5042	0.0923	38	0.4158	-0.0752
9	-0.4483	0.0929	39	0.3670	-0.0744
10	-0.3925	0.0921	40	0.3183	-0.0737
11	-0.3368	0.0902	41	0.2696	-0.0730
12	-0.2811	0.0873	42	0.2210	-0.0724
13	-0.2256	0.0836	43	0.1724	-0.0719
14	-0.1701	0.0792	44	0.1238	-0.0714
15	-0.1147	0.0743	45	0.0753	-0.0711
16	-0.0593	0.0688	46	0.0268	-0.0710
17	-0.0040	0.0630	47	-0.0217	-0.0711
18	0.0513	0.0567	48	-0.0701	-0.0715
19	0.1065	0.0501	49	-0.1186	-0.0722
20	0.1618	0.0431	50	-0.1671	-0.0733
21	0.2171	0.0358	51	-0.2155	-0.0749
22	0.2723	0.0281	52	-0.2640	-0.0771
23	0.3276	0.0201	53	-0.3125	-0.0801
24	0.3829	0.0117	54	-0.3609	-0.0840
25	0.4381	0.0028	55	-0.4092	-0.0891
26	0.4934	-0.0066	56	-0.4575	-0.0957
27	0.5487	-0.0165	57	-0.5054	-0.1043
28	0.6040	-0.0271	58	-0.5529	-0.1154
29	0.6593	-0.0385	59	-0.5994	-0.1301
30	0.7144	-0.0507	60	-0.6446	-0.1499

TURBINE STATOR VANE COORDINATES   TNC 11795   PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-59.4146	0.09535	0.01503	8.60600

STATION	X	Y	STATION	X	Y
1	-0.8013	-0.0611	31	0.7523	-0.0611
2	-0.7937	-0.0238	32	0.7369	-0.0761
3	-0.7763	0.0066	33	0.6856	-0.0746
4	-0.7346	0.0459	34	0.6343	-0.0733
5	-0.6832	0.0715	35	0.5832	-0.0722
6	-0.6276	0.0861	36	0.5323	-0.0711
7	-0.5707	0.0933	37	0.4815	-0.0701
8	-0.5134	0.0962	38	0.4311	-0.0694
9	-0.4561	0.0969	39	0.3808	-0.0687
10	-0.3989	0.0961	40	0.3305	-0.0680
11	-0.3417	0.0942	41	0.2804	-0.0674
12	-0.2846	0.0915	42	0.2303	-0.0668
13	-0.2276	0.0879	43	0.1802	-0.0663
14	-0.1707	0.0837	44	0.1302	-0.0659
15	-0.1138	0.0789	45	0.0802	-0.0657
16	-0.0569	0.0737	46	0.0303	-0.0655
17	-0.0001	0.0680	47	-0.0197	-0.0656
18	0.0567	0.0619	48	-0.0696	-0.0660
19	0.1134	0.0556	49	-0.1195	-0.0666
20	0.1702	0.0488	50	-0.1695	-0.0677
21	0.2270	0.0418	51	-0.2194	-0.0692
22	0.2838	0.0344	52	-0.2693	-0.0714
23	0.3406	0.0266	53	-0.3192	-0.0743
24	0.3975	0.0183	54	-0.3691	-0.0781
25	0.4543	0.0096	55	-0.4189	-0.0832
26	0.5113	0.0002	56	-0.4686	-0.0898
27	0.5686	-0.0101	57	-0.5180	-0.0984
28	0.6259	-0.0212	58	-0.5669	-0.1097
29	0.6833	-0.0333	59	-0.6148	-0.1247
30	0.7408	-0.0465	60	-0.6613	-0.1453

TURBINE STATOR VANE COORDINATES TNC 11795 PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-60.7492	0.09538	0.01509	8.92000

STATION	X	Y	STATION	X	Y
1	-0.8182	-0.0671	31	0.8041	-0.0671
2	-0.8118	-0.0327	32	0.7882	-0.0822
3	-0.7935	0.0012	33	0.7338	-0.0794
4	-0.7505	0.0428	34	0.6790	-0.0770
5	-0.6971	0.0700	35	0.6246	-0.0748
6	-0.6393	0.0855	36	0.5705	-0.0730
7	-0.5800	0.0933	37	0.5167	-0.0714
8	-0.5205	0.0966	38	0.4632	-0.0699
9	-0.4610	0.0975	39	0.4099	-0.0687
10	-0.4016	0.0970	40	0.3569	-0.0677
11	-0.3424	0.0953	41	0.3040	-0.0668
12	-0.2833	0.0927	42	0.2514	-0.0660
13	-0.2243	0.0894	43	0.1989	-0.0654
14	-0.1653	0.0854	44	0.1466	-0.0650
15	-0.1063	0.0808	45	0.0944	-0.0647
16	-0.0473	0.0758	46	0.0423	-0.0647
17	0.0117	0.0703	47	-0.0097	-0.0649
18	0.0707	0.0645	48	-0.0616	-0.0654
19	0.1298	0.0582	49	-0.1135	-0.0662
20	0.1890	0.0516	50	-0.1654	-0.0674
21	0.2484	0.0445	51	-0.2173	-0.0691
22	0.3080	0.0370	52	-0.2691	-0.0715
23	0.3677	0.0288	53	-0.3210	-0.0746
24	0.4277	0.0201	54	-0.3728	-0.0787
25	0.4679	0.0106	55	-0.4245	-0.0841
26	0.5483	0.0003	56	-0.4761	-0.0910
27	0.6090	-0.0110	57	-0.5275	-0.1001
28	0.6700	-0.0235	58	-0.5783	-0.1120
29	0.7312	-0.0372	59	-0.6282	-0.1281
30	0.7928	-0.0525	60	-0.6763	-0.1504

TURBINE STATOR VANE COORDINATES   INC 11795   PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-62.1125	0.09543	0.01513	9.19600

STATION	X	Y	STATION	X	Y
1	-0.8329	-0.0755	31	0.8596	-0.0755
2	-0.8279	-0.0449	32	0.8434	-0.0906
3	-0.8087	-0.0062	33	0.7866	-0.0868
4	-0.7647	0.0387	34	0.7293	-0.0833
5	-0.7095	0.0686	35	0.6723	-0.0803
6	-0.6493	0.0863	36	0.6157	-0.0777
7	-0.5874	0.0956	37	0.5594	-0.0754
8	-0.5251	0.0999	38	0.5033	-0.0733
9	-0.4628	0.1015	39	0.4476	-0.0716
10	-0.4007	0.1014	40	0.3921	-0.0701
11	-0.3387	0.1000	41	0.3368	-0.0688
12	-0.2768	0.0976	42	0.2817	-0.0677
13	-0.2150	0.0942	43	0.2267	-0.0668
14	-0.1533	0.0901	44	0.1720	-0.0662
15	-0.0917	0.0854	45	0.1173	-0.0657
16	-0.0300	0.0801	46	0.0628	-0.0656
17	0.0317	0.0744	47	0.0084	-0.0657
18	0.0934	0.0681	48	-0.0460	-0.0662
19	0.1553	0.0614	49	-0.1003	-0.0670
20	0.2172	0.0543	50	-0.1546	-0.0683
21	0.2793	0.0466	51	-0.2088	-0.0702
22	0.3416	0.0384	52	-0.2630	-0.0727
23	0.4041	0.0295	53	-0.3173	-0.0761
24	0.4669	0.0199	54	-0.3715	-0.0805
25	0.5298	0.0094	55	-0.4257	-0.0862
26	0.5931	-0.0021	56	-0.4797	-0.0936
27	0.6565	-0.0147	57	-0.5335	-0.1033
28	0.7203	-0.0285	58	-0.5868	-0.1161
29	0.7842	-0.0439	59	-0.6389	-0.1334
30	0.8485	-0.0609	60	-0.6890	-0.1577

TURBINE STATOR VANE COORDINATES   TNC 11795   PAGE

THETA	LEADING RADIUS	TRAILING RADIUS	SECTION DIAMETER
-62.1125	0.09543	0.01513	9.51000

STATION	X	Y	STATION	X	Y
1	-0.8329	-0.0755	31	0.8596	-0.0755
2	-0.8279	-0.0449	32	0.8434	-0.0906
3	-0.8087	-0.0062	33	0.7866	-0.0868
4	-0.7647	0.0387	34	0.7293	-0.0833
5	-0.7095	0.0686	35	0.6723	-0.0803
6	-0.6493	0.0863	36	0.6157	-0.0777
7	-0.5874	0.0956	37	0.5594	-0.0754
8	-0.5251	0.0999	38	0.5033	-0.0733
9	-0.4628	0.1015	39	0.4476	-0.0716
10	-0.4007	0.1014	40	0.3921	-0.0701
11	-0.3387	0.1000	41	0.3368	-0.0688
12	-0.2768	0.0976	42	0.2817	-0.0677
13	-0.2150	0.0942	43	0.2267	-0.0668
14	-0.1533	0.0901	44	0.1720	-0.0662
15	-0.0917	0.0854	45	0.1173	-0.0657
16	-0.0300	0.0801	46	0.0628	-0.0656
17	0.0317	0.0744	47	0.0084	-0.0657
18	0.0934	0.0681	48	-0.0460	-0.0662
19	0.1553	0.0614	49	-0.1003	-0.0670
20	0.2172	0.0543	50	-0.1546	-0.0683
21	0.2793	0.0466	51	-0.2088	-0.0702
22	0.3416	0.0384	52	-0.2630	-0.0727
23	0.4041	0.0295	53	-0.3173	-0.0761
24	0.4669	0.0199	54	-0.3715	-0.0805
25	0.5298	0.0094	55	-0.4257	-0.0862
26	0.5931	-0.0021	56	-0.4797	-0.0936
27	0.6565	-0.0147	57	-0.5335	-0.1033
28	0.7203	-0.0285	58	-0.5868	-0.1161
29	0.7842	-0.0439	59	-0.6389	-0.1334
30	0.8485	-0.0609	60	-0.6890	-0.1577

APPENDIX B

SAMPLE DATA SETS FOR LINEAR AND ANNULAR CASCADES

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 8:28:44

INLET CONDITIONS

PTOTLE	PSTATIC	TTOTLE	MACH #	V/V*	REY/10**6
43.32	42.37	1279.82	.180	.195	.379

STANTON CALCULATION INPUT

RHO -LBM/IN3 *10**4	VELOCITY - IN/HR	STREAM TEMPERATURE - F
.52033	13614608.	812.66

CP - BTU/LBM/F
.257

MASS FLOW RATE

ORIFICE 6.32 CASCADE

IDEAL EXIT CONDITIONS

PTOTLE	STATIC	TTOTAL	MACH #	V/V*	REY/10**6
43.32	31.57	1279.82	.696	.725	1.193

CASCADE OPERATING CONDITION

EXPANSION RATIO= 1.372 STATIC PRESSURE RATIO= .745

*** ENDWALL HEAT TRANSFER ***

RUN # 116 DATE: 12/11/79 TIME: 8:35:27

HOT SIDE ENDWALL TEMPERATURES

TC#	X	Y	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
51	[illegible]	.400	520.2	520.6	-.4	-.287
52	[illegible]	.887	768.2*	864.8	-96.6	-61.450
53	[illegible]	1.773	497.1	497.6	-.5	-.343
54	[illegible]	2.270	499.7	500.4	-.7	-.468
55	[illegible]	2.600	498.6	499.3	-.7	-.471
56	.225	2.126	-345.9*	-358.9	13.0	8.139
57	.439	.226	535.4	535.8	-.4	-.251
58	.439	.959	514.7	514.9	-.2	-.155
59	.439	1.693	506.4	507.0	-.6	-.354
60	.439	2.426	504.7	506.0	-1.3	-.782
61	.548	1.920	505.7	506.4	-.7	-.410
62	.700	1.176	517.6	518.1	-.4	-.274
63	.756	1.496	511.7	512.3	-.6	-.361
64	.768	2.300	513.0	514.2	-1.2	-.753
65	1.050	.814	529.9	531.0	-1.1	-.654
66	1.050	1.338	520.5	520.8	-.4	-.217
67	1.050	1.862	513.9	514.6	-.6	-.459
68	1.050	2.386	228.7*	-401.3	629.9	379.665
69	1.352	1.178	525.7	526.5	-.8	-.483
70	1.375	1.761	792.7*	1044.9	-252.2	-150.956
71	1.465	2.258	522.5	523.3	-.8	-.474
72	1.406	2.734	526.4	526.8	-.3	-.287
73	1.650	1.728	532.6	533.2	-.6	-.338
74	1.650	2.106	529.8	531.1	-1.3	-.775
75	1.650	2.624	-208.6*	603.0	-811.6	-478.136
76	1.650	3.082	534.5	535.1	-.6	-.326
77	1.800	2.092	715.8*	726.2	-10.4	-6.098
78	2.058	2.448	539.8	541.0	-1.3	-.761
79	1.810	3.000	542.8	544.2	-1.4	-.791
80	1.875	3.553	537.3	538.2	-1.0	-.562
81	1.809	2.531	533.0	533.9	-.9	-.521
82	2.058	3.040	-224.5*	-226.1	1.6	.923
83	2.058	3.487	547.1	548.3	-1.2	-.680
84	2.058	4.006	539.1	540.1	-1.0	-.585
85	2.252	2.898	548.2	549.2	-1.0	-.554
86	2.250	3.418	776.8*	1092.7	-315.9	-179.647
87	2.250	3.990	549.8	550.4	-.6	-.341
88	2.250	4.480	547.4	548.2	-.8	-.477
89	2.474	3.008	540.9	542.4	-1.6	-.876
90	2.474	3.338	546.6	547.8	-1.2	-.659
91	2.474	4.578	553.4	554.2	-.8	-.459
92	2.474	3.958	552.3	553.3	-1.1	-.590
93	2.474	5.195	558.2	558.9	-.7	-.403
94	2.554	3.300	553.2	553.8	-.6	-.316
95	2.710	3.791	551.6	553.1	-1.5	-.814
96	2.710	4.465	553.0	554.5	-1.5	-.815
97	2.710	5.179	212.3*	220.5	-8.1	-4.473
98	2.974	2.942	563.5	564.9	-1.4	-.759
99	2.974	3.620	541.1	541.9	-.8	-.421
100	2.974	4.296	545.4	546.3	-.9	-.517

101	2.974	5.075	837.7*	565.7	272.0	147.780
102	2.974	5.851	576.1	577.4	-1.4	-.732
103	2.974	6.628	584.6	585.8	-1.2	-.668

TWAVE = 534.2
TG = 807.4
TW/TG = .784

*** ENDWALL HEAT TRANSFER ***

RUN # 116 DATE: 12/11/79 TIME: 8:35:38

COLD SIDE ENDWALL TEMPERATURES

TC#	X	Y	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
104	[illegible]	[illegible]	4110.9*	4110.1	.8	.437
105	[illegible]	.807	444.0	444.4	-.5	-.259
106	[illegible]	1.773	445.7	446.0	-.4	-.209
107	[illegible]	2.800	437.0	437.6	-.6	-.341
108	.409	.226	472.3	472.7	-.4	-.226
109	.409	.959	464.9	465.4	-.5	-.247
110	.409	1.693	460.1	460.7	-.6	-.295
111	.409	2.426	454.1	454.8	-.6	-.335
112	1.058	.814	469.1*	463.8	5.3	2.775
113	1.058	1.338	512.6*	456.6	56.0	29.378
114	1.058	1.862	473.1	473.7	-.6	-.302
115	1.058	2.386	753.6*	980.7	-227.1	-118.412
116	1.658	1.705	470.9	471.4	-.6	-.301
117	1.658	2.166	481.9	482.7	-.8	-.389
118	1.658	2.624	485.8	486.6	-.8	-.397
119	1.658	3.082	491.7	492.5	-.7	-.374
120	2.058	2.448	487.4	488.1	-.7	-.371
121	2.058	2.967	1549.9*	1556.0	-6.1	-3.129
122	2.058	3.487	861.6*	720.2	141.4	72.291
123	2.058	4.006	500.5	501.3	-.8	-.431
124	2.474	3.008	288.8*	288.9	-.2	-.088
125	2.474	3.338	-5.5*	819.5	-825.0	-418.254
126	2.474	3.958	503.7	504.5	-.7	-.367
127	2.474	4.578	515.6	516.4	-.9	-.445
128	2.474	5.198	-464.5*	-465.2	.7	.352
129	2.974	2.942	474.5	475.2	-.7	-.359
130	2.974	3.620	483.3	484.2	-1.0	-.477
131	2.974	4.298	119.5*	119.5	-.2	-.016
132	2.974	5.075	509.3	510.1	-.8	-.405
133	2.974	5.851	1036.5*	106.6	929.9	461.360
134	2.974	6.626	1477.9*	1229.6	248.2	122.790

TWAVE = 476.6
TG = 607.4
TW/TG = .739

*** ENDWALL HEAT TRANSFER ***

RUN # 116 DATE: 12/11/79 TIME: 8:42:25

SUCTION SURFACE TEMPERATURES

******************************** EXTERNAL ********************************

PERCENT CHORD	TC #	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
		*** 5% SPAN ***			
2.0	51	519.7	520.3	-.6	-.275
10.0	52	492.6	492.3	.3	.155
20.6	53	467.8	467.7	.0	.021
31.2	54	475.5	476.2	-.7	-.350
42.0	55	487.0	487.6	-.6	-.265
52.4	56	461.6	462.1	-.5	-.245
62.9	57	468.9	469.4	-.5	-.233
73.1	58	486.1	486.7	-.6	-.259
83.6	59	493.7	494.5	-.8	-.366
100.0	60	617.0	616.3	.8	.357
		*** 20% SPAN ***			
4.6	70	536.9	536.6	.3	.146
14.0	71	492.3	492.2	.0	.007
24.0	72	472.4	472.7	-.3	-.146
35.5	73	496.6	497.1	-.4	-.197
45.6	74	521.5	522.4	-.9	-.425
56.3	75	502.9	503.8	-1.0	-.432
66.8	76	537.2	538.4	-1.2	-.534
77.2	77	558.9	559.9	-1.0	-.468
87.3	78	570.2	571.3	-1.[illegible]	-.468
100.0	79	656.9*	657.4	-.5	-.239
		*** MID SPAN ***			
.7	90	565.9	565.8	.1	.054
7.1	91	548.9	548.2	.7	.322
17.4	92	845.5*	403.8	441.7	191.150
27.9	93	515.9	514.5	1.4	.612
38.7	94	531.4	530.6	.9	.382
49.2	95	535.2	534.1	1.2	.498
59.6	96	543.7	542.7	1.0	.444
69.9	97	622.2	621.3	.9	.386
80.3	98	593.6	593.0	.8	.361
93.8	99	665.0*	663.6	1.5	.619
100.0	100	673.4*	672.4	1.0	.417

SUCTION SURFACE TEMPERATURES

******************************** INTERNAL ********************************

PERCENT CHORD	TC #	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
		*** 5% SPAN ***			
4.4	110	485.7	486.1	-.3	-.142
9.0	111	452.4	452.4	.0	.011
18.2	112	412.5	412.6	-.1	-.041
25.0	113	415.8	416.3	-.5	-.204
35.3	114	446.5	446.3	.2	.099
45.9	115	459.5	459.2	.2	.100
57.6	116	437.6	437.4	.2	.101
66.9	117	454.3	454.0	.3	.116
77.5	118	263.2*	888.5	-625.3	-254.869
89.5	119	548.7	548.9	-.2	-.065
		*** 20% SPAN ***			
5.3	128	282.6*	511.8	-229.2	-91.392
11.4	129	471.8	472.1	-.3	-.104
20.2	130	422.1	422.3	-.2	-.078
28.2	131	446.6	446.9	-.2	-.089
39.3	132	485.9	486.0	-.2	-.067
49.7	133	478.8	478.7	.1	.027
60.3	134	513.5	513.3	.3	.107
70.9	135	544.8	544.7	.0	.019
81.3	136	555.9	556.0	-.1	-.034
89.5	137	150.0*	150.0	.0	.003
		*** MID SPAN ***			
7.2	146	960.2*	517.0	443.2	170.011
13.5	147	491.7	491.2	.5	.186
22.0	148	454.1	453.3	.8	.307
30.3	149	479.3	478.2	1.2	.441
42.6	150	513.7	512.6	1.1	.414
52.6	151	501.8	500.5	1.3	.503
63.0	152	563.8	562.4	1.4	.535
74.2	153	604.3	603.0	1.3	.493
84.7	154	34.7*	-133.9	168.5	63.583
89.5	155	647.4	646.0	1.4	.525

AVERAGE OF 2 READINGS

*** ENDWALL HEAT TRANSFER ***

RUN # 116 DATE: 12/11/79 TIME: 8:42:39

PRESSURE SURFACE TEMPERATURES

******************************** EXTERNAL ********************************

PERCENT CHORD	TC #	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
		*** 5% SPAN ***			
1.8	61	539.9	539.3	.6	.266
11.7	62	454.6	454.5	.0	.007
22.1	63	425.8	425.9	-.1	-.063
32.7	64	430.9	431.1	-.2	-.094
43.5	65	416.8*	911.2	-494.4	-228.608
54.2	66	450.2	450.0	.2	.078
65.0	67	471.3	470.8	.5	.240
75.6	68	484.9	485.0	-.1	-.046
86.3	69	513.9	513.3	.7	.308
		*** 20% SPAN ***			
.5	80	583.5	583.8	-.3	-.144
8.2	81	531.8	532.1	-.3	-.140
18.3	82	453.6	453.8	-.1	-.065
28.9	83	437.3	437.6	-.3	-.120
39.6	84	93.1*	93.0	.1	.049
50.5	85	-99.1*	-212.6	113.5	49.938
61.1	86	464.3	464.6	-.3	-.129
71.6	87	499.1	499.4	-.3	-.140
82.5	88	541.4	541.4	.0	.004
94.4	89	634.9	634.6	.3	.123
		*** MID SPAN ***			
4.8	101	580.1	579.3	.8	.345
14.9	102	477.0	476.7	.3	.130
25.4	103	434.2	434.4	-.1	-.055
36.1	104	435.9	435.4	.5	.209
47.0	105	446.2	445.8	.4	.155
57.6	106	463.2	462.8	.4	.181
68.3	107	444.9*	515.4	-70.5	-29.446
79.0	108	1480.8*	1493.4	-12.6	-5.254
89.7	109	645.5	646.5	-1.0	-.411

PRESSURE SURFACE TEMPERATURES

******************************** INTERNAL ********************************

PERCENT CHORD	TC #	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
		*** 5% SPAN ***			
6.7	120	491.9	492.3	-.4	-.163
15.7	121	401.0	401.2	-.2	-.089
26.6	122	392.9	393.1	-.2	-.065
37.6	123	418.2	418.5	-.3	-.117
48.7	124	439.4	439.8	-.4	-.174
59.6	125	446.7	447.8	-1.0	-.419
70.3	126	454.9	456.0	-1.1	-.450
81.1	127	476.4	477.4	-1.0	-.395
		*** 20% SPAN ***			
5.1	138	536.4	536.4	-.1	-.026
11.8	139	453.9	454.0	-.1	-.049
22.9	140	409.6	409.7	-.1	-.047
35.3	141	-1561.0*	-1646.7	85.7	33.208
45.0	142	436.6	436.8	-.2	-.079
57.4	143	438.0	438.4	-.4	-.140
66.3	144	464.4	464.7	-.2	-.089
77.1	145	490.4	490.6	-.3	-.105
		*** MID SPAN ***			
4.0	156	577.2	576.3	.9	.331
8.9	157	514.3	513.6	.7	.247
20.2	158	420.4	419.9	.4	.152
30.0	159	401.9	401.6	.3	.107
41.3	160	422.0	421.7	.3	.103
52.2	161	442.2	441.9	.3	.103
62.9	162	470.1	470.2	-.1	-.042
73.6	163	-4938.5*	-5006.0	67.5	25.016

*** ENDWALL HEAT TRANSFER ***

RUN # 116 DATE: 12/11/79 TIME: 8:48:17

ADIABATIC ENDWALL TEMPERATURES

TC#	X	Y	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
1	3.009	5.619	685.6	685.0	.6	.423
2	3.009	5.175	686.5	686.0	.5	.321
3	3.009	4.731	687.3	686.8	.5	.321
4	3.009	4.287	690.5	690.0	.5	.340
5	3.009	3.843	691.7	690.6	1.1	.669
6	3.009	3.399	694.1	692.9	1.3	.827
7	3.009	2.955	783.2*	568.6	214.6	137.780
8	2.749	5.619	694.4	693.3	1.2	.739
9	2.749	5.175	699.2	697.5	1.6	1.030
10	2.749	4.731	-1176.3*	-1213.3	37.0	23.491
11	2.749	4.287	-1181.5*	-997.6	-183.9	-116.425
12	2.749	3.843	696.6	695.4	1.2	.752
13	2.749	3.399	694.8	694.1	.7	.448
14	2.749	2.955	700.4	699.7	.6	.400
15	2.469	5.385	4497.1*	4488.6	8.5	5.294
16	2.469	5.100	-5540.5*	-5394.1	-146.4	-91.194
17	2.469	4.845	708.2	707.1	1.0	.640
18	2.469	4.590	300.0*	299.7	.3	.198
19	2.469	4.335	777.2x	780.1	-2.9	-1.767
20	2.469	4.080	701.3	700.5	.7	.457
21	2.469	3.570	694.1	693.4	.7	.423
22	2.469	3.060	714.1	713.6	.6	.352
23	2.359	4.961	712.5	711.2	1.3	.760
24	2.359	4.740	711.1*	689.5	21.6	13.095
25	2.359	4.489	2160.4*	2159.9	.5	.294
26	2.359	4.236	698.6	696.5	2.1	1.249
27	2.229	4.618	710.6	708.5	2.1	1.287
28	2.229	4.400	725.2 x	723.9	1.3	.782
29	2.229	4.152	698.4	696.4	1.9	1.151
30	2.229	3.904	328.4*	306.3	22.1	13.137
31	2.229	3.656	693.1	691.2	1.9	1.127
32	2.229	3.160	696.2	694.7	1.4	.841
33	2.229	2.694	-470.0*	-378.4	-91.6	-53.867
34	2.099	4.254	700.7	699.8	1.0	.559
35	2.099	4.050	698.5	697.8	.7	.408
36	2.099	3.816	694.5	694.2	.3	.162
37	1.969	3.910	-514.2*	-520.1	5.8	3.391
38	1.969	3.720	692.6	692.4	.4	.223
39	1.969	3.500	689.4	689.2	.2	.090
40	1.969	3.060	690.7	690.8	-.1	-.079
41	1.969	2.620	692.2	692.1	.1	.037
42	1.969	2.210	-1584.0*	-1582.1	-1.9	-1.087
43	1.839	3.600	667.1	666.5	.6	.345
44	1.709	3.318	-527.2*	-532.5	5.4	3.047
45	1.709	2.950	689.6	689.1	.5	.264
46	1.709	2.552	690.2	689.7	.6	.310
47	1.709	2.154	-801.2*	-871.6	70.4	39.624
48	1.709	1.786	-1427.5*	-1518.7	91.1	51.123
49	1.449	2.845	-1066.8*	-1072.2	5.4	3.225
50	1.449	2.490	692.8	692.1	.7	.40[illegible]

AD-A110 332 GENERAL MOTORS CORP INDIANAPOLIS IN DETROIT DIESEL A--ETC F/G 21/5
EXPERIMENTAL INVESTIGATION OF TURBINE ENDWALL HEAT TRANSFER. VO--ETC(U)
AUG 81 L D HYLTON, M S MIHELC, E R TURNER F33615-77-C-2030
UNCLASSIFIED DDA-EDR-10363-VOL-1 AFWAL-TR-81-2077-VOL-1 NL

2 OF 2
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END
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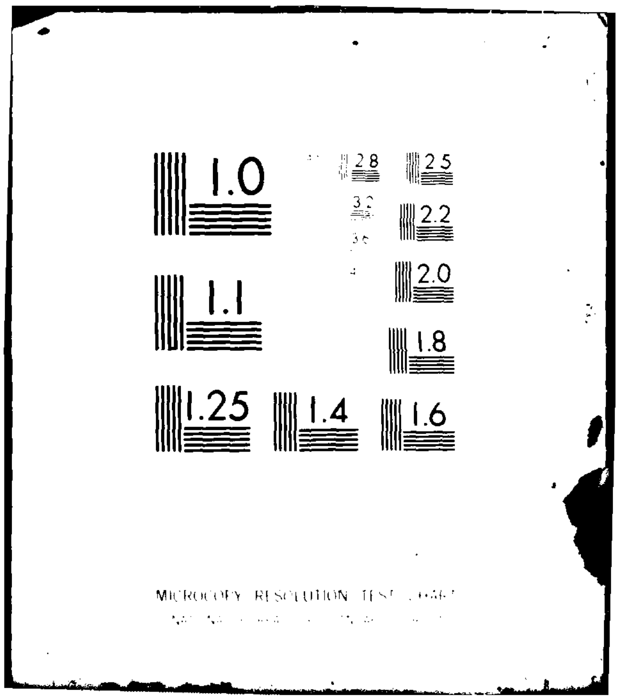

1.0
2.8
2.5
3.2
2.2
3.6
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION

51	1.449	2.105	689.6	689.0	.6	.329
52	1.449	1.720	695.0	694.3	.7	.361
53	1.449	1.565	-3200.7*	-3201.3	.6	.321
54	1.189	2.532	728.8	729.3	-.5	-.262
55	1.189	2.160	691.6	692.4	-.6	-.333
56	1.189	1.758	687.6	687.9	-.3	-.169
57	1.189	1.356	694.0	695.0	-1.1	-.579
58	1.189	.964	-3298.9*	-3303.1	4.2	2.286
59	1.059	2.310	-1102.5*	-1104.4	-3.0	-1.655
60	.929	2.411	1.5*	6.9	-5.3	-2.879
61	.929	2.085	693.6	693.3	.3	.163
62	.929	1.725	6014.4*	5733.0	281.5	151.391
63	.929	1.373	683.3	683.5	-.2	-.114
64	.929	1.017	-1409.0*	-1425.0	16.0	8.544
65	.929	.691	689.7	689.4	.2	.123
66	.799	2.240	701.6	702.0	-.5	-.254
67	.669	2.397	807.1*	805.7	1.4	.726
68	.669	2.030	696.1	696.5	-.3	-.184
69	.669	1.633	684.4	684.9	-.5	-.255
70	.669	1.236	681.5	681.8	-.3	-.161
71	.669	.839	684.8	685.0	-.1	-.071
72	.669	.472	682.5	683.5	-1.0	-.504
73	.539	2.330	-1181.2*	-1185.5	4.3	2.244
74	.409	2.527	-1412.1*	-1378.3	-33.9	-17.583
75	.409	2.220	708.7	708.7	-.0	-.010
76	.409	1.893	-17.3*	-24.2	6.9	3.573
77	.409	1.566	684.0	683.7	.3	.169
78	.409	1.239	-2385.5*	-2591.4	206.0	105.758
79	.409	.912	686.6	686.4	.2	.125
80	.409	.585	681.3	681.1	.2	.100
81	.409	.258	680.1	679.8	.4	.180
82	.279	2.416	1516.3*	2043.6	-527.2	-267.741
83	.279	2.064	704.6	705.0	-.4	-.211
84	.149	2.660	721.7	723.7	-2.0	-1.011
85	.149	2.304	714.7	717.3	-2.5	-1.274
86	.149	1.946	698.4	700.5	-2.1	-1.057
87	.149	1.592	684.0	685.6	-1.6	-.804
88	.149	1.056	676.4	676.8	-.4	-.223
89	.149	.524	672.9	672.8	.1	.048
90	.149	-.010	-2015.9*	-2256.8	240.9	119.673

AVERAGE OF 2 READINGS

AVERAGE 695.9

GPA 2D TURBINE VANE CASCADE

RUN #115 DATE: 12/11/79 TIME: 0:53:54

EXIT SURVEY: SPAN= 50.0% PROBE ANGLE= 72.06 VANE # 4

PROBE TRAVERSE RAW DATA

POSITION	P1	P1	P2	P3	P4	P5	TT2
13.645	43.450	43.401	32.304	32.590	32.386	32.822	764.5
13.760	43.455	43.401	32.306	32.600	32.433	32.863	763.8
13.906	43.450	43.383	32.393	32.609	32.452	32.881	759.3
14.042	43.432	43.302	32.418	32.636	32.466	32.911	776.0
14.177	43.454	43.334	32.435	32.653	32.506	32.933	755.9
14.308	43.450	43.290	32.455	32.675	32.534	32.946	769.4
14.441	43.450	43.158	32.401	32.685	32.555	32.951	775.2
14.572	43.472	42.948	32.456	32.664	32.553	32.921	765.1
14.706	43.452	42.654	32.430	32.667	32.544	32.875	786.2
14.839	43.444	42.337	32.406	32.695	32.530	32.823	781.1
14.971	43.451	42.102	32.366	32.723	32.521	32.771	784.9
15.102	43.466	42.042	32.327	32.768	32.528	32.736	776.8
15.236	43.475	42.200	32.287	32.810	32.525	32.704	787.2
15.369	43.445	42.445	32.226	32.817	32.500	32.658	798.0
15.500	43.448	42.716	32.151	32.802	32.474	32.614	789.5
15.566	43.484	42.938	32.111	32.779	32.442	32.573	778.8
15.633	43.487	43.074	32.073	32.748	32.412	32.533	789.9
15.699	43.482	43.163	32.024	32.690	32.363	32.480	793.6
15.764	43.462	43.227	31.961	32.601	32.288	32.401	773.6
15.874	43.473	43.287	31.915	32.496	32.221	32.323	779.4
15.978	43.489	43.338	31.866	32.355	32.141	32.242	779.1
16.066	43.504	43.372	31.823	32.208	32.067	32.167	765.4
16.136	43.505	43.361	31.803	32.095	32.013	32.120	764.3
16.191	43.483	43.373	31.803	32.039	31.998	32.099	761.8
16.294	43.515	43.370	31.825	31.991	31.999	32.094	744.4

SIDEWALL STATIC PRESSURES

INLET STATICS

42.42 42.45 42.50 42.42 42.52 42.57 42.44 42.46 42.41

EXIT STATICS - ROW 1

31.47 14.60 32.75 30.81 32.95 31.53 33.19 31.22 32.60

EXIT STATICS - ROW 2

31.46 31.39 31.59 31.67 31.50 31.75 31.78 31.72 31.84 32.07 32.20 31.44 31.25

INLET CORE RAKES

Y	TEMPERATURES		PRESSURES		MACH #		VELCCITY	
.500	779.2	736.5	43.29	43.49	.166	.187	286.	313.
1.000	873.9	749.6	43.59	43.48	.196	.185	347.	311.
1.500	815.1	762.5	33.73	43.50	.000	.188	.	318.
2.000	-771.3	-1437.	43.61	42.86	.002	.254	.	.
2.500	-1592.	750.2	43.64	43.48	.248	.187	.	314.

INLET BOUNDARY LAYER RAKES

YT	YP1	YP2	TEMPS	PRESSURES		MACH #		VELCCITY	
.000	.000	.000	808.9	39.46	43.21	.000	.168	.	.
.020	.042	.037	-21249	43.24	42.89	.172	.127	.	.
.040	.057	.062	-28374	43.03	25.39	.149	.002	.	.
.060	.077	.077	260.7	43.33	43.27	.172	.165	277.	266.
.080	.092	.102	711.1	37.07	43.32	.000	.176	.	534.
.100	.112	.127	2900.4	43.35	14.58	.179	.002	539.	.
.140	.152	.167	-1313.	14.57	43.38	.000	.176	.	284.
.180	.192	.212	714.4	14.57	14.58	.000	.002	.	.
.220	.232	.247	-1414.	43.41	43.40	.196	.194	.	.
.260	.267	.287	231.3	30.34	43.38	.000	.192	.	.
.300	.302	.332	682.3	34.10	43.43	.000	.195	.	.
.340	.337	.362	-15670	43.47	15.50	.199	.002	.	.
.380	.367	.402	721.4	37.55	43.42	.002	.210	.	.
.420	.402	.432	20.8	43.48	43.40	.218	.002	.	.
.460	.442	.477	800.8	43.48	40.04	.000	.332	.	260.
.500	.477	.507	-1741.	43.42	42.60	.000	.078	.	.

VANE STATIC PRESSURES

PRESSURE SURFACE 5% SPAN	PRESSURE SURFACE 20% SPAN	PRESSURE SURFACE 50% SPAN		SUCTION SURFACE 5% SPAN	SUCTION SURFACE 20% SPAN	SUCTION SURFACE 50% SPAN
41.44	31.16	34.34	*	38.49	38.51	33.96
43.06	43.15	35.82	*	31.02	33.16	36.02
22.59	42.79	42.98	*	31.92	31.05	17.57
35.14	42.75	34.01	*	32.16	30.23	29.80
42.19	42.55	42.59	*	24.72	30.42	29.72
38.79	36.62	41.56	*	18.66	31.76	31.09
41.23	41.06	41.14	*	33.54	30.66	30.94
39.95	39.89	36.14	*	31.41	31.27	31.88
37.44	37.66	37.76	*	16.70	31.42	31.17
34.25	33.03	34.01	*	16.55	29.86	31.69
32.24	48.54	32.43	*			
31.64	31.70	31.51	*			

ENDWALL PRESSURES

AXIAL STATION	SUCTION ENDWALL	25 % PASSAGE	50 % PASSAGE	75 % PASSAGE	PRESSURE ENDWALL
1	42.70	42.26	42.44	30.41	42.45
2	41.10	41.70	42.34	42.75	42.96
3	35.81	39.91	41.59	42.25	42.78
4	32.24	36.03	38.56	40.24	41.32
5	30.47	31.42	33.50	15.94	38.48
6	31.19	31.09	31.25	31.45	32.31
7	32.45	31.52	31.31	31.55	32.28
8	31.69	31.74	31.79	31.69	31.77
8	31.99	31.88			

INLET PROBE UNCORRECTED

DWALL	P REF	P	T1	T2	T3
1.498	43.54	43.53	776.0	774.4	776.0
1.450	43.55	43.55	774.3	766.3	777.8
1.400	43.54	43.56	769.6	780.8	769.0
1.349	43.54	43.57	778.2	776.0	773.6
1.301	43.55	43.60	775.0	765.2	772.9
1.251	43.56	43.60	769.6	762.3	765.3
1.201	43.55	43.61	776.5	772.2	783.5
1.149	43.55	43.62	777.1	771.4	771.3
1.099	43.54	43.61	775.6	770.0	771.6
1.051	43.56	43.62	762.5	778.8	770.5
1.000	43.53	43.61	775.1	762.7	775.8
.950	43.55	43.62	774.4	769.9	776.9
.901	43.54	43.62	770.6	773.3	771.3
.850	43.53	43.61	771.7	781.3	768.5
.799	43.53	43.62	772.2	790.4	776.6
.750	43.53	43.61	772.1	770.6	770.6
.700	43.52	43.60	768.8	758.9	773.1
.651	43.53	43.61	772.0	770.0	759.8
.600	43.53	43.59	767.4	779.2	768.0
.549	43.52	43.59	765.6	780.9	764.6
.499	43.53	43.60	775.2	771.6	769.7
.461	43.53	43.60	770.1	772.6	762.6
.420	43.53	43.59	762.3	764.3	761.7
.380	43.50	43.57	757.8	768.2	753.9
.341	43.49	43.57	766.0	762.1	767.8
.301	43.50	43.56	754.1	755.1	757.5
.260	43.49	43.53	759.9	757.7	756.9
.220	43.48	43.50	754.5	751.3	751.9
.180	43.50	43.48	744.8	743.9	751.9
.140	43.50	43.43	733.5	745.0	754.0
.100	43.48	43.36	736.7	743.8	723.3
.081	43.47	43.28	721.3	728.7	729.5
.061	43.48	43.18	707.2	705.9	716.6
.040	43.46	43.10	703.2	702.6	712.2
.018	43.46	42.92	690.0	684.0	686.6
.015	43.46	42.92	688.8	690.6	701.0

INLET PROBE CORRECTED

Y	ANGLE	TEMP	PRES	MACH #	VELOCITY
.015	.07	693.5	43.00	.135	223.
.018	.23	686.8	43.01	.136	224.
.040	1.17	706.0	43.21	.159	264.
.061	2.06	709.9	43.26	.165	273.
.081	2.69	726.5	43.37	.176	293.
.100	3.69	734.6	43.44	.183	306.
.140	5.35	744.2	43.48	.186	312.
.180	6.96	746.9	43.52	.192	319.
.220	8.55	752.6	43.54	.192	324.
.260	10.15	758.2	43.55	.193	326.
.301	11.74	755.6	43.55	.193	325.
.341	13.27	765.3	43.57	.194	329.
.380	14.75	760.0	43.56	.193	327.
.420	16.23	762.8	43.54	.192	325.
.461	17.77	768.4	43.54	.192	325.
.499	19.18	772.2	43.54	.192	326.
.549	20.99	770.3	43.54	.192	325.
.600	22.84	771.6	43.53	.191	324.
.651	24.67	767.3	43.54	.192	325.
.700	26.44	766.9	43.54	.192	325.
.750	28.22	771.1	43.55	.192	326.
.799	29.95	779.7	43.55	.193	326.
.850	31.75	773.9	43.55	.192	327.
.901	33.53	771.7	43.54	.191	325.
.950	35.28	773.7	43.54	.192	326.
1.000	37.01	771.2	43.55	.192	326.
1.051	38.83	770.6	43.53	.191	324.
1.099	40.51	772.4	43.54	.192	326.
1.149	42.29	773.2	43.54	.192	326.
1.201	44.10	777.4	43.54	.191	326.
1.251	45.88	765.7	43.52	.190	322.
1.301	47.67	771.0	43.54	.192	326.
1.349	49.42	775.9	43.53	.191	325.
1.400	51.24	773.1	43.53	.191	324.
1.450	53.11	772.8	43.53	.191	324.
1.498	54.65	775.5	43.54	.192	326.

GMA200 TURBINE VANE CASCADE

RUN # 116 DATE: 12/11/79 TIME: 9:24:12

EXIT SURVEY: SPAN= 50.3% PROBE ANGLE= 72.05 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.990	43.458	43.394	32.193	32.458	32.391	32.570	752.0
11.120	43.491	43.409	32.200	32.469	32.430	32.559	747.7
11.256	43.493	43.427	32.220	32.536	32.471	32.580	750.7
11.389	43.504	43.439	32.232	32.559	32.484	32.596	736.8
11.522	43.491	43.439	32.245	32.576	32.490	32.622	732.0
11.655	43.494	43.422	32.245	32.562	32.474	32.637	730.7
11.789	43.481	43.353	32.247	32.546	32.462	32.650	732.2
11.923	43.492	43.245	32.244	32.563	32.427	32.646	735.3
12.053	43.496	42.975	32.247	32.477	32.406	32.640	746.7
12.187	43.530	42.654	32.236	32.441	32.367	32.617	747.5
12.321	43.513	42.319	32.221	32.428	32.329	32.581	749.0
12.453	43.533	42.118	32.202	32.432	32.310	32.575	748.1
12.587	43.548	42.143	32.195	32.453	32.300	32.572	759.1
12.720	43.553	42.352	32.195	32.460	32.320	32.610	759.2
12.851	43.587	42.672	32.215	32.501	32.337	32.640	766.2
12.918	43.603	42.934	32.250	32.528	32.373	32.701	762.7
12.982	43.613	43.117	32.260	32.545	32.387	32.726	764.3
13.048	43.620	43.243	32.302	32.554	32.405	32.758	765.0
13.116	43.606	43.326	32.322	32.565	32.422	32.779	762.1
13.224	43.610	43.411	32.352	32.583	32.444	32.794	762.8
13.330	43.628	43.478	32.382	32.601	32.469	32.837	764.9
13.435	43.648	43.539	32.427	32.626	32.490	32.874	759.7
13.485	43.639	43.562	32.444	32.632	32.495	32.903	762.4
13.539	43.619	43.576	32.401	32.652	32.512	32.930	759.5
13.658	43.623	43.594	32.472	32.675	32.526	32.945	760.5

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 9:32:26

EXIT SURVEY: SPAN= 40.6% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.981	43.647	43.550	32.379	32.530	32.403	32.855	749.2
11.119	43.642	43.591	32.350	32.550	32.449	32.790	747.1
11.252	43.623	43.625	32.359	32.594	32.498	32.778	736.5
11.391	43.657	43.656	32.377	32.632	32.532	32.800	736.0
11.522	43.671	43.673	32.389	32.646	32.537	32.809	729.8
11.655	43.642	43.637	32.379	32.633	32.529	32.820	721.9
11.769	43.645	43.597	32.362	32.618	32.518	32.817	736.4
11.921	43.651	43.472	32.373	32.587	32.498	32.816	727.0
12.054	43.667	43.260	32.370	32.553	32.465	32.790	742.3
12.187	43.642	42.937	32.348	32.521	32.430	32.754	748.3
12.319	43.634	42.602	32.313	32.489	32.376	32.688	753.3
12.456	43.622	42.354	32.276	32.485	32.346	32.651	745.5
12.587	43.661	42.356	32.261	32.505	32.337	32.639	756.9
12.721	43.670	42.573	32.262	32.548	32.368	32.669	761.4
12.851	43.675	42.876	32.266	32.560	32.382	32.685	754.6
12.917	43.680	43.117	32.292	32.586	32.420	32.721	768.2
12.982	43.702	43.298	32.317	32.604	32.446	32.746	755.4
13.049	43.736	43.435	32.351	32.625	32.480	32.788	755.8
13.117	43.728	43.530	32.378	32.642	32.502	32.808	765.6
13.224	43.719	43.607	32.397	32.646	32.511	32.826	767.0
13.328	43.725	43.670	32.431	32.666	32.540	32.868	760.7
13.436	43.764	43.729	32.480	32.697	32.570	32.922	761.5
13.485	43.763	43.748	32.508	32.720	32.590	32.961	764.3
13.538	43.744	43.749	32.526	32.737	32.601	32.986	768.0
13.648	43.752	43.752	32.545	32.758	32.617	33.014	756.3

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 9:40:24

EXIT SURVEY: SPAN= 29.6% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.961	43.896	43.752	32.588	32.679	32.553	33.082	744.4
11.123	43.917	43.847	32.575	32.739	32.628	33.000	738.1
11.256	43.907	43.877	32.571	32.785	32.680	32.988	733.3
11.391	43.945	43.918	32.592	32.822	32.710	32.998	732.0
11.522	43.908	43.905	32.593	32.839	32.726	33.021	738.6
11.655	43.945	43.921	32.608	32.847	32.732	33.048	741.9
11.758	43.935	43.880	32.612	32.842	32.740	33.069	737.0
11.921	43.957	43.779	32.617	32.812	32.723	33.064	734.5
12.054	43.924	43.535	32.603	32.767	32.695	33.038	735.5
12.157	43.941	43.206	32.605	32.733	32.667	33.010	753.3
12.321	43.908	42.888	32.605	32.731	32.649	32.959	753.9
12.453	43.952	42.639	32.572	32.733	32.638	32.903	746.4
12.587	43.950	42.608	32.545	32.758	32.636	32.849	757.1
12.719	43.936	42.784	32.517	32.776	32.651	32.824	757.4
12.851	43.971	43.120	32.521	32.807	32.682	32.830	759.0
12.917	43.959	43.372	32.525	32.821	32.709	32.847	762.8
12.961	43.955	43.554	32.547	32.845	32.732	32.864	755.1
13.047	43.917	43.644	32.541	32.831	32.723	32.863	759.0
13.115	43.929	43.731	32.548	32.833	32.736	32.889	755.8
13.224	43.934	43.795	32.568	32.850	32.747	32.908	753.2
13.328	43.942	43.860	32.587	32.868	32.766	32.952	759.8
13.436	43.934	43.900	32.611	32.869	32.774	32.987	758.2
13.484	43.925	43.905	32.620	32.892	32.768	33.014	757.2
13.538	43.927	43.916	32.645	32.916	32.768	33.058	756.7
13.646	43.935	43.923	32.661	32.938	32.794	33.094	763.9

GMA 200 TURBINE VANE CASCADE

RUN #115 DATE: 12/11/79 TIME: 9:48:18

EXIT SURVEY: SPAN= 25.7% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.951	43.965	43.840	32.670	32.775	32.648	33.137	749.3
11.121	43.966	43.917	32.639	32.818	32.705	33.063	749.9
11.256	43.957	43.934	32.634	32.849	32.726	33.032	741.0
11.389	43.961	43.936	32.627	32.863	32.740	33.048	740.3
11.522	43.968	43.947	32.637	32.879	32.750	33.070	729.6
11.655	43.961	43.923	32.638	32.876	32.752	33.102	722.3
11.789	43.946	43.834	32.633	32.847	32.728	33.097	733.4
11.921	43.931	43.649	32.612	32.800	32.699	33.077	735.6
12.055	43.955	43.396	32.609	32.771	32.675	33.045	734.3
12.187	43.933	43.044	32.588	32.741	32.649	32.988	738.4
12.319	43.965	42.733	32.576	32.736	32.630	32.928	744.7
12.453	43.929	42.534	32.541	32.746	32.620	32.867	754.2
12.587	43.975	42.623	32.529	32.782	32.640	32.834	751.1
12.720	43.968	42.885	32.519	32.818	32.679	32.824	755.2
12.852	43.969	43.236	32.523	32.848	32.723	32.832	751.5
12.916	43.975	43.477	32.534	32.867	32.756	32.848	748.6
12.981	43.972	43.626	32.547	32.878	32.773	32.857	754.9
13.048	44.009	43.749	32.566	32.893	32.796	32.889	754.2
13.114	44.000	43.830	32.589	32.968	32.820	32.917	748.3
13.221	44.023	43.989	32.611	32.917	32.824	32.945	754.8
13.328	43.995	43.937	32.631	32.931	32.834	32.990	747.0
13.436	44.000	43.970	32.663	32.956	32.846	33.038	741.9
13.455	44.044	44.004	32.696	32.985	32.864	33.093	740.6
13.556	44.052	44.027	32.730	33.014	32.877	33.133	743.4
13.651	44.034	44.006	32.739	33.034	32.864	33.176	738.2

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 9:56: 4

EXIT SURVEY: SPAN= 20.3% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.981	44.069	43.850	32.724	32.891	32.731	33.188	727.0
11.120	44.069	43.982	32.725	32.931	32.797	33.107	723.1
11.256	44.075	44.017	32.739	32.974	32.849	33.112	722.6
11.389	44.099	44.030	32.749	32.994	32.863	33.129	713.3
11.522	44.070	43.957	32.748	32.998	32.864	33.151	714.3
11.655	44.065	43.789	32.732	32.977	32.840	33.159	713.6
11.791	44.095	43.502	32.721	32.954	32.822	33.171	719.9
11.923	44.094	43.114	32.691	32.919	32.765	33.148	731.7
12.055	44.084	42.600	32.658	32.907	32.751	33.113	730.7
12.189	44.073	42.311	32.622	32.910	32.719	33.052	733.2
12.323	44.075	42.156	32.580	32.930	32.710	33.002	732.0
12.455	44.067	42.312	32.567	32.977	32.740	32.953	749.1
12.587	44.073	42.639	32.530	32.988	32.759	32.910	732.8
12.722	44.058	43.062	32.534	33.017	32.805	32.895	741.7
12.853	44.043	43.415	32.529	33.022	32.847	32.900	740.8
12.917	44.060	43.662	32.553	33.033	32.873	32.906	738.5
12.981	44.063	43.789	32.565	33.031	32.883	32.914	736.1
13.049	44.053	43.861	32.570	33.031	32.891	32.928	737.4
13.116	44.020	43.897	32.570	33.022	32.864	32.931	734.9
13.225	44.049	43.954	32.590	33.028	32.886	32.961	741.4
13.329	44.026	43.976	32.612	33.035	32.869	32.997	722.2
13.436	44.029	43.986	32.637	33.045	32.862	33.030	722.8
13.466	44.017	43.982	32.649	33.048	32.874	33.060	723.0
13.538	44.009	43.972	32.663	33.060	32.878	33.090	723.1
13.630	44.028	43.985	32.692	33.081	32.883	33.127	718.3

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10: 4: 5

EXIT SURVEY: SPAN= 16.0% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.961	44.051	43.721	32.679	32.904	32.725	33.108	707.8
11.123	44.024	43.899	32.674	32.958	32.799	33.035	710.9
11.255	44.037	43.945	32.665	32.993	32.824	33.004	704.3
11.391	44.036	43.904	32.660	33.024	32.843	33.023	707.6
11.523	44.052	43.785	32.664	33.038	32.836	33.036	710.8
11.654	44.012	43.482	32.631	33.011	32.798	33.049	711.9
11.789	44.004	43.048	32.594	32.975	32.732	33.044	718.9
11.921	44.040	42.557	32.549	32.950	32.682	33.060	724.0
12.054	44.041	42.096	32.499	32.934	32.627	33.042	730.4
12.189	44.039	41.783	32.441	32.933	32.584	33.014	730.0
12.323	44.000	41.721	32.397	32.951	32.580	32.963	734.2
12.453	44.035	41.932	32.377	32.986	32.620	32.938	738.5
12.587	44.025	42.357	32.380	33.016	32.663	32.904	742.5
12.721	44.016	42.812	32.393	33.025	32.747	32.886	735.4
12.853	44.013	43.241	32.425	33.033	32.798	32.869	729.7
12.917	44.029	43.492	32.449	33.029	32.835	32.876	724.7
12.981	44.023	43.650	32.485	33.044	32.870	32.890	729.6
13.047	44.040	43.769	32.520	33.043	32.865	32.969	731.3
13.114	44.053	43.841	32.548	33.046	32.894	32.927	726.6
13.223	44.049	43.908	32.581	33.055	32.906	32.951	711.3
13.328	44.071	43.959	32.614	33.062	32.910	32.987	716.9
13.436	44.049	43.973	32.647	33.083	32.923	33.030	718.1
13.485	44.064	43.991	32.678	33.096	32.926	33.065	714.1
13.538	44.064	43.983	32.690	33.097	32.925	33.093	702.4
13.649	44.035	43.959	32.713	33.109	32.933	33.129	710.1

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:11:28

EXIT SURVEY: SPAN= 12.8% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.981	44.074	43.692	32.710	32.966	32.796	33.108	694.0
11.123	44.083	43.908	32.711	33.014	32.876	33.026	693.7
11.256	44.063	43.959	32.714	33.060	32.918	32.997	702.8
11.389	44.091	43.890	32.708	33.086	32.929	32.994	698.5
11.522	44.085	43.688	32.696	33.097	32.901	32.993	690.6
11.655	44.075	43.333	32.663	33.092	32.849	33.010	703.2
11.788	44.112	42.893	32.626	33.085	32.774	33.032	719.2
11.923	44.079	42.412	32.558	33.074	32.690	33.054	712.1
12.054	44.087	42.044	32.490	33.052	32.603	33.066	711.3
12.187	44.071	41.817	32.420	33.054	32.562	33.079	723.6
12.319	44.083	41.822	32.373	33.055	32.560	33.073	722.8
12.453	44.075	42.047	32.352	33.067	32.602	33.051	723.2
12.587	44.075	42.413	32.356	33.062	32.670	33.024	730.4
12.721	44.088	42.862	32.400	33.070	32.754	33.003	724.3
12.853	44.072	43.242	32.449	33.064	32.826	32.985	723.8
12.916	44.056	43.480	32.490	33.054	32.856	32.962	723.3
12.981	44.050	43.622	32.510	33.033	32.868	32.945	715.2
13.048	44.056	43.733	32.551	33.040	32.896	32.954	715.4
13.114	44.048	43.799	32.576	33.039	32.909	32.958	715.5
13.221	44.055	43.862	32.602	33.035	32.914	32.968	701.5
13.329	44.027	43.903	32.631	33.038	32.916	32.987	704.8
13.434	44.055	43.939	32.661	33.045	32.924	33.012	698.3
13.485	44.030	43.937	32.666	33.049	32.927	33.036	709.7
13.540	44.015	43.923	32.701	33.044	32.928	33.066	725.6
13.549	44.020	43.905	32.725	33.042	32.933	33.110	706.2

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:18:45

EXIT SURVEY: SPAN= 9.8% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.981	44.069	43.624	32.683	32.938	32.774	33.063	696.4
11.120	44.059	43.831	32.665	32.998	32.875	32.984	699.8
11.256	44.058	43.687	32.663	33.046	32.934	32.945	686.0
11.388	44.071	43.851	32.690	33.082	32.963	32.928	695.7
11.522	44.066	43.680	32.665	33.100	32.944	32.916	703.1
11.655	44.045	43.364	32.664	33.109	32.890	32.911	698.1
11.788	44.046	43.410	32.625	33.118	32.804	32.920	705.9
11.919	44.057	42.684	32.561	33.112	32.693	32.942	714.2
12.054	44.064	42.318	32.500	33.098	32.609	32.999	719.1
12.187	44.064	42.107	32.431	33.072	32.539	33.060	710.3
12.320	44.054	41.994	32.372	33.045	32.515	33.106	722.0
12.453	44.057	42.049	32.351	33.022	32.538	33.113	708.6
12.586	44.046	42.259	32.361	33.009	32.595	33.089	716.3
12.721	44.057	42.600	32.405	33.000	32.673	33.049	717.7
12.851	44.063	42.972	32.463	32.995	32.757	33.014	707.8
12.918	44.068	43.243	32.521	33.000	32.818	32.995	706.0
12.981	44.050	43.421	32.555	32.991	32.855	32.974	709.3
13.049	44.057	43.563	32.602	33.004	32.902	32.978	708.4
13.114	44.065	43.663	32.631	33.000	32.922	32.969	728.9
13.223	44.046	43.743	32.654	32.996	32.930	32.961	704.4
13.330	43.988	43.777	32.659	32.968	32.915	32.950	702.7
13.433	43.934	43.780	32.661	32.932	32.888	32.950	704.4
13.485	43.902	43.763	32.657	32.894	32.858	32.956	695.5
13.538	43.857	43.731	32.647	32.847	32.819	32.955	700.9
13.650	43.808	43.649	32.629	32.769	32.775	32.974	703.0

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:24:41

EXIT SURVEY: SPAN= 6.8% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.961	43.780	43.244	32.458	32.676	32.557	32.798	699.8
11.120	43.775	43.475	32.463	32.732	32.668	32.729	692.8
11.254	43.770	43.526	32.460	32.778	32.721	32.699	683.3
11.388	43.766	43.512	32.462	32.814	32.760	32.689	690.9
11.522	43.772	43.433	32.403	32.839	32.775	32.684	691.7
11.654	43.779	43.300	32.454	32.850	32.755	32.681	685.7
11.788	43.787	43.071	32.435	32.852	32.695	32.685	694.6
11.920	43.793	42.787	32.405	32.847	32.604	32.706	695.1
12.054	43.778	42.504	32.360	32.833	32.497	32.756	703.4
12.187	43.790	42.245	32.314	32.804	32.361	32.829	705.2
12.320	43.798	41.990	32.252	32.773	32.290	32.899	714.0
12.453	43.804	41.743	32.202	32.760	32.247	32.939	718.9
12.586	43.812	41.619	32.182	32.774	32.261	32.941	720.4
12.721	43.827	41.665	32.190	32.801	32.319	32.898	709.0
12.853	43.823	41.948	32.215	32.832	32.402	32.847	706.1
12.916	43.827	42.220	32.241	32.853	32.466	32.808	710.7
12.981	43.834	42.487	32.279	32.890	32.541	32.792	703.4
13.037	43.843	42.741	32.309	32.913	32.599	32.781	711.8
13.114	43.844	42.934	32.333	32.920	32.637	32.773	707.9
13.223	43.850	43.148	32.368	32.939	32.687	32.788	695.2
13.330	43.851	43.346	32.407	32.952	32.725	32.812	699.7
13.435	43.855	43.491	32.449	32.960	32.757	32.857	701.4
13.486	43.853	43.575	32.488	32.971	32.778	32.900	696.1
13.540	43.839	43.608	32.511	32.964	32.762	32.937	697.9
13.649	43.841	43.609	32.535	32.943	32.778	32.985	705.3

SIDEWALL STATIC PRESSURES

INLET STATICS

42.45 42.47 42.47 42.50 42.49 42.49 42.47 42.43 41.27

EXIT STATICS - ROW 1

31.44 14.60 32.74 30.80 32.96 31.55 33.22 31.13 32.57

EXIT STATICS - ROW 2

31.42 31.37 31.59 31.67 31.49 31.76 31.79 31.65 31.65 31.84 31.99 31.47 31.24

INLET CORE RAKES

Y	TEMPERATURES		PRESSURES		MACH #		VELOCITY	
.500	784.6	730.1	43.29	43.44	.181	.194	309.	324.
1.000	611.6	752.3	43.53	43.41	.202	.192	349.	323.
1.500	611.5	763.5	34.36	43.44	.000	.194	.	329.
2.000	-545.6	-1126.	43.55	42.84	.000	.222	.	.
2.500	-1613.	770.1	43.56	43.48	.253	.198	.	336.

INLET BOUNDARY LAYER RAKES

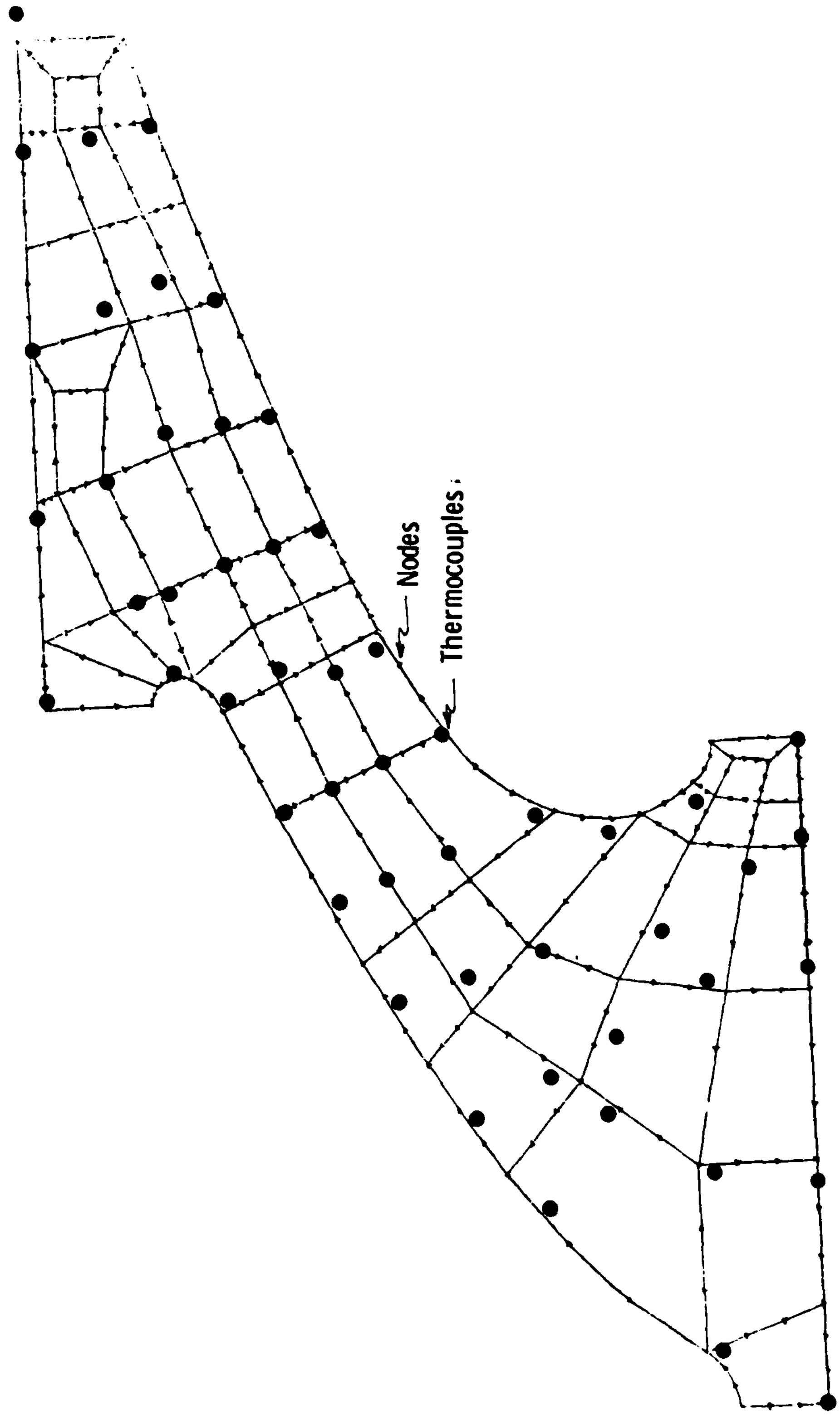
YT	YP1	YP2	TEMPS	PRESSURES		MACH #		VELOCITY	
.000	.008	.006	814.2	39.36	43.20	.000	.181	.	.
.020	.042	.037	-20625	43.22	42.69	.184	.145	.	.
.040	.057	.062	-28299	42.98	25.39	.158	.000	.	.
.060	.077	.077	483.3	43.32	43.25	.184	.176	335.	323.
.080	.092	.102	714.7	37.05	43.31	.000	.166	.	597.
.100	.112	.127	3666.1	43.34	14.57	.192	.000	599.	.
.140	.152	.167	-681.9	14.57	43.35	.000	.186	.	286.
.180	.192	.212	693.9	14.57	14.57	.000	.000	.	.
.220	.232	.247	-1357.	43.40	43.39	.206	.204	.	.
.260	.267	.287	295.6	39.44	43.37	.000	.201	.	.
.300	.302	.332	641.0	34.05	43.41	.000	.204	.	.
.340	.337	.362	-17930	43.47	15.49	.210	.000	.	.
.380	.367	.402	753.9	37.54	43.30	.000	.215	.	.
.420	.402	.432	-53.4	43.40	43.38	.223	.000	.	.
.460	.442	.477	794.6	43.47	40.04	.151	.000	129.	.
.500	.477	.507	-229.0	43.40	42.56	.189	.000	233.	11.

VANE STATIC PRESSURES

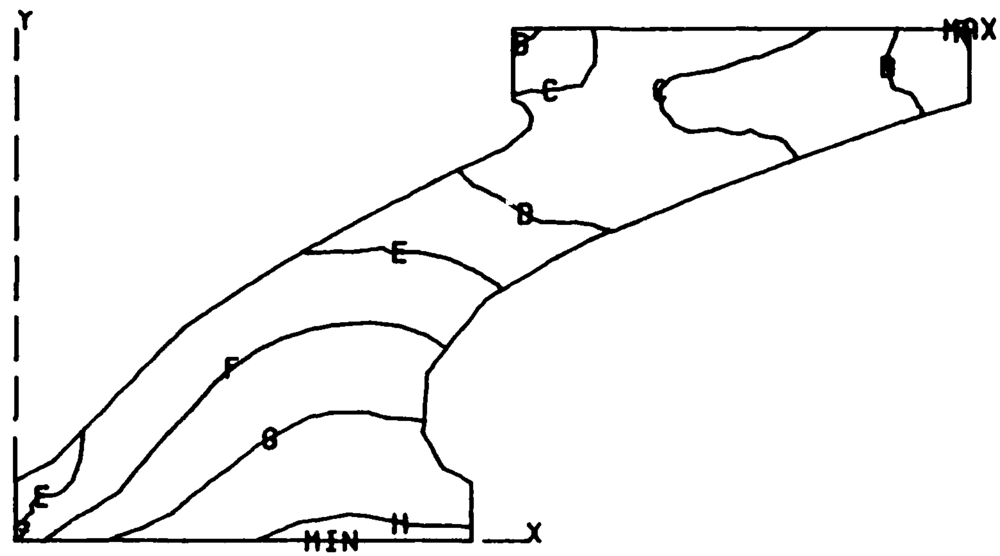
PRESSURE SURFACE 5% SPAN	PRESSURE SURFACE 20% SPAN	PRESSURE SURFACE 50% SPAN		SUCTION SURFACE 5% SPAN	SUCTION SURFACE 20% SPAN	SUCTION SURFACE 50% SPAN
41.43	31.02	34.33	*	38.52	38.50	34.14
43.45	43.13	35.81	*	31.71	33.29	36.03
22.30	42.77	42.98	*	31.93	31.06	17.79
35.06	42.74	34.04	*	32.21	30.24	29.80
42.17	42.54	42.57	*	24.72	30.44	29.96
38.77	38.65	41.55	*	18.82	31.66	31.06
41.21	41.37	41.13	*	33.02	30.69	30.97
39.92	39.88	36.04	*	31.44	31.27	31.79
37.42	37.06	37.76	*	16.89	31.47	31.19
34.24	33.00	34.01	*	16.71	29.89	31.75
32.34	48.64	32.43	*			
31.03	31.70	31.49	*			

ENDWALL PRESSURES

AXIAL STATION	SUCTION ENDWALL	25 % PASSAGE	50 % PASSAGE	75 % PASSAGE	PRESSURE ENDWALL
1	42.67	42.22	42.45	31.16	42.46
2	41.16	41.72	42.30	42.75	42.96
3	35.80	39.68	41.64	42.27	42.80
4	32.26	36.04	38.55	40.24	41.35
5	30.49	31.44	33.51	15.86	38.49
6	31.19	31.10	31.28	31.46	32.33
7	32.48	31.52	31.32	31.57	32.29
8	31.65	31.77	31.82	31.71	31.76
8	31.97	31.86			

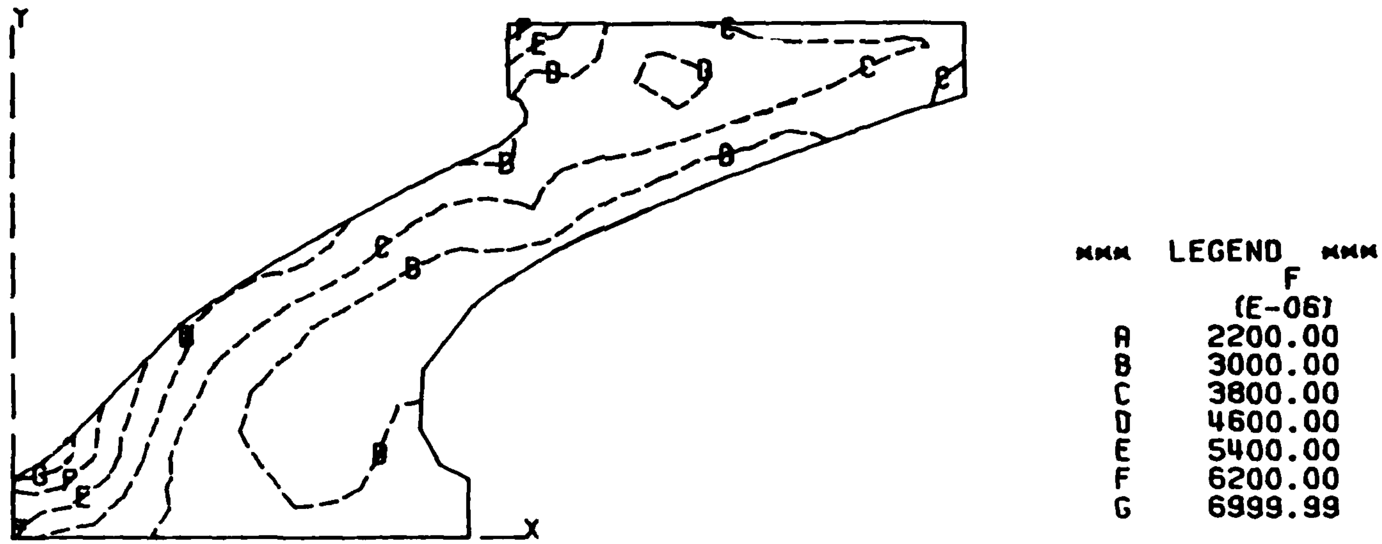


Nodes
Thermocouples

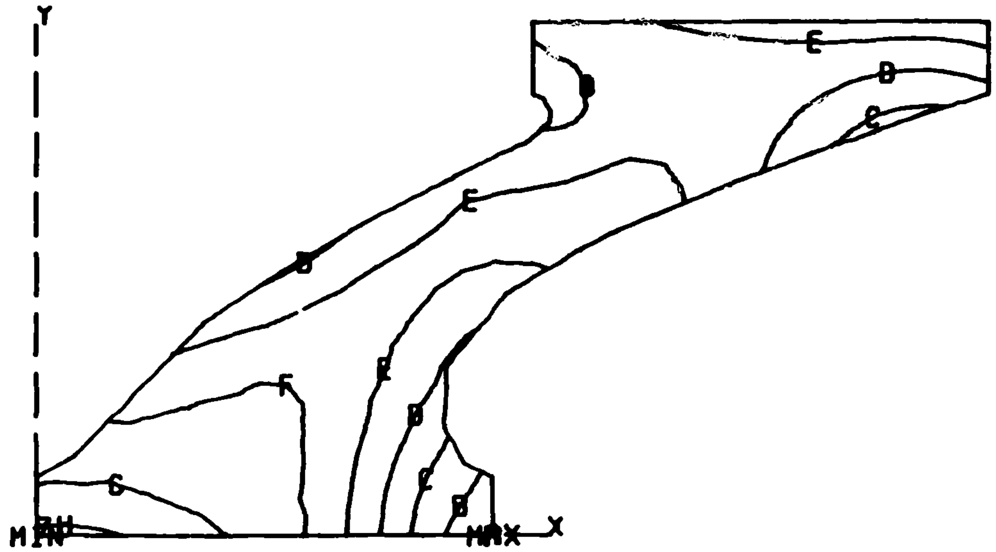


*** LEGEND ***	F
A	570.00
B	560.00
C	550.00
D	540.00
E	530.00
F	520.00
G	510.00
H	500.00
MAX	571.17
MIN	497.33

RUN 116 MACH .7 TGAS 800. RE 1.2E06 HEAT TRANSFER ENDWALL
CONTOUR PLOT OF TEMPERATURE
SCALE = 1.0000 PLOT TIME AND DATE = 12:36:35 80/003



RUN 116 MACH .7 TGAS 800. RE 1.2E06 HEAT TRANSFER ENDWALL
CONTOUR PLOT OF STANTON NUMBER.
SCALE = 1.0000 PLOT TIME AND DATE = 12:39:52 80/C03



*** LEGEND ***	
UNITS = TEMP	
SYMBOL	CONTOUR
A	7.25000E 02
B	7.17000E 02
C	7.09000E 02
D	7.01000E 02
E	6.93000E 02
F	6.85000E 02
G	6.77000E 02
H	6.69000E 02
MAX	7.25496E 02
MIN	6.66625E 02

RUN 116 MACH .7 TGAS 800. RE 1.2E06 ADIABATIC ENDWALL
CONTOUR PLOT OF TEMPERATURE
SCALE = 1.0000 PLOT TIME AND DATE = 12:47:44 79/347

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:19:40

EXIT SURVEY: SPAN= 50.3% PROBE ANGLE= 72.09 VANE # 3

PROBE TRAVERSE RAW DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.990	43.468	43.394	32.193	32.458	32.391	32.570	752.0
11.120	43.491	43.409	32.200	32.489	32.430	32.559	747.7
11.256	43.493	43.427	32.220	32.536	32.471	32.580	750.7
11.389	43.504	43.439	32.232	32.559	32.484	32.596	736.8
11.522	43.491	43.439	32.245	32.576	32.490	32.622	732.0
11.655	43.494	43.422	32.245	32.562	32.474	32.637	730.7
11.789	43.481	43.353	32.247	32.546	32.462	32.650	732.2
11.923	43.492	43.205	32.244	32.503	32.427	32.646	735.3
12.053	43.496	42.975	32.247	32.477	32.406	32.640	746.7
12.187	43.530	42.654	32.236	32.441	32.367	32.617	747.5
12.321	43.513	42.319	32.221	32.428	32.329	32.581	749.0
12.453	43.533	42.118	32.202	32.432	32.310	32.575	748.1
12.587	43.540	42.143	32.195	32.453	32.300	32.572	759.1
12.720	43.553	42.352	32.195	32.480	32.320	32.610	759.2
12.851	43.567	42.672	32.215	32.501	32.337	32.640	766.2
12.918	43.603	42.934	32.250	32.528	32.373	32.701	762.7
12.982	43.613	43.117	32.280	32.545	32.387	32.726	764.3
13.048	43.620	43.243	32.302	32.554	32.405	32.758	765.0
13.116	43.608	43.326	32.322	32.565	32.422	32.779	762.1
13.224	43.610	43.411	32.352	32.583	32.444	32.794	762.8
13.330	43.628	43.478	32.382	32.601	32.469	32.837	764.9
13.435	43.640	43.539	32.427	32.626	32.490	32.874	759.7
13.485	43.639	43.562	32.444	32.632	32.495	32.903	762.4
13.539	43.619	43.576	32.461	32.652	32.512	32.930	759.5
13.650	43.623	43.594	32.472	32.675	32.526	32.945	760.5

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:22:10

EXIT SURVEY: SPAN= 50.3% PROBE ANGLE= 72.09 VANE # 3

TIME CORRECTED & SMOOTHED DATA

POSITION	PT	P1	P2	P3	P4	P5	TT2
10.990	43.468	43.336	32.150	32.415	32.347	32.527	752.0
11.120	43.491	43.335	32.147	32.439	32.375	32.508	749.7
11.256	43.493	43.341	32.155	32.466	32.401	32.512	744.9
11.389	43.504	43.349	32.166	32.491	32.418	32.532	739.1
11.522	43.491	43.355	32.178	32.508	32.424	32.555	733.4
11.655	43.494	43.344	32.187	32.506	32.419	32.577	730.3
11.789	43.481	43.280	32.191	32.483	32.401	32.591	732.9
11.923	43.492	43.118	32.187	32.445	32.370	32.587	737.9
12.053	43.496	42.857	32.175	32.405	32.331	32.564	742.8
12.187	43.530	42.541	32.156	32.366	32.289	32.534	746.6
12.321	43.513	42.237	32.136	32.344	32.249	32.505	749.2
12.453	43.533	42.021	32.116	32.345	32.220	32.483	752.2
12.587	43.540	42.012	32.098	32.357	32.208	32.480	756.1
12.720	43.553	42.220	32.090	32.369	32.210	32.496	760.4
12.851	43.567	42.549	32.097	32.380	32.220	32.529	763.7
12.918	43.603	42.730	32.109	32.386	32.227	32.551	764.3
12.982	43.613	42.899	32.128	32.392	32.238	32.576	764.1
13.048	43.620	43.040	32.149	32.401	32.253	32.600	763.9
13.116	43.608	43.130	32.169	32.412	32.269	32.622	763.6
13.224	43.610	43.208	32.199	32.427	32.290	32.648	763.2
13.330	43.628	43.262	32.228	32.441	32.306	32.675	762.7
13.435	43.640	43.312	32.260	32.456	32.321	32.711	761.6
13.465	43.639	43.336	32.277	32.468	32.331	32.732	761.0
13.539	43.619	43.358	32.293	32.483	32.343	32.753	760.5
13.650	43.623	43.381	32.313	32.514	32.366	32.783	760.5

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:22:48

EXIT SURVEY: SPAN= 50.3% PROBE ANGLE= 72.09 VANE # 3

X FCD DPT V2	Y %P DPT/PTX V2AX	PT PT1 OMEGA V2TAN	PS PT1/PS2 EBAR V2SPN	M V/V*2 DS/CP TT2	YAW V/V*I SPR	PITCH BETA2 MASS
4.606	10.990	43.34	31.68	.693	-.909	-.616
.360	-75.68	43.41	1.370	.722	.724	18.82
.070	.002	.0060	.0049	-.0432	.748	.5744
1123.	362.2	1062.	-12.1	1216.		
4.606	11.120	43.34	31.69	.692	-1.003	-.458
.360	-70.78	43.41	1.370	.722	.723	18.92
.071	.002	.0060	.0050	-.0470	.748	.5781
1120.	363.1	1059.	-9.0	1214.		
4.606	11.256	43.34	31.71	.692	-1.070	-.383
.360	-65.67	43.41	1.369	.721	.723	18.98
.065	.002	.0055	.0046	-.0487	.749	.5805
1118.	363.8	1057.	-7.5	1209.		
4.606	11.389	43.35	31.73	.691	-1.119	-.390
.360	-60.68	43.41	1.368	.721	.722	19.03
.057	.001	.0048	.0040	-.0489	.749	.5819
1118.	364.4	1056.	-7.6	1203.		
4.606	11.522	43.36	31.74	.691	-1.137	-.449
.360	-55.66	43.41	1.368	.720	.722	19.05
.051	.001	.0043	.0036	-.0481	.750	.5822
1117.	364.7	1056.	-8.8	1198.		
4.606	11.655	43.35	31.75	.690	-1.103	-.546
.360	-50.67	43.41	1.367	.720	.721	19.02
.061	.001	.0052	.0043	-.0471	.750	.5805
1117.	364.0	1056.	-10.6	1194.		
4.606	11.789	43.28	31.75	.689	-1.024	-.661
.360	-45.63	43.41	1.367	.718	.721	18.94
.126	.003	.0107	.0089	-.0463	.750	.5765
1115.	361.8	1054.	-12.9	1197.		
4.606	11.923	43.12	31.74	.684	-.931	-.764
.360	-40.60	43.41	1.368	.714	.722	18.85
.288	.007	.0244	.0204	-.0461	.750	.5701
1108.	357.9	1049.	-14.8	1202.		

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:22:55

X	Y	PT	PS	M	YAW	PITCH
FCD	%P	PT1	PT1/PS2	V/V*2	V/V*I	BETA2
DPT	DPT/PTX	OMEGA	EBAR	DS/CP	SPR	MASS
V2	V2AX	V2TAN	V2SPN	TT2		
4.606	12.053	42.86	31.73	.678	-.859	-.840
.360	-35.72	43.41	1.368	.708	.722	18.77
.549	.013	.0465	.0390	-.0470	.749	.5624
1096.	352.8	1038.	-16.1	1207.		
4.606	12.187	42.55	31.72	.669	-.808	-.907
.360	-30.66	43.41	1.368	.700	.722	18.72
.864	.020	.0732	.0616	-.0494	.749	.5546
1082.	347.2	1024.	-17.1	1211.		
4.606	12.321	42.24	31.72	.661	-.822	-.972
.360	-25.64	43.41	1.369	.692	.723	18.74
1.169	.027	.0991	.0837	-.0524	.749	.5490
1067.	342.7	1010.	-18.1	1213.		
4.606	12.453	42.03	31.72	.655	-.904	-1.022
.360	-20.66	43.41	1.369	.686	.723	18.82
1.384	.032	.1173	.0994	-.0555	.749	.5470
1055.	340.4	998.9	-18.8	1216.		
4.606	12.587	42.02	31.71	.655	-.989	-1.055
.360	-15.64	43.41	1.369	.686	.723	18.90
1.393	.032	.1180	.1000	-.0567	.749	.5496
1055.	341.6	997.5	-19.4	1220.		
4.606	12.720	42.23	31.70	.661	-1.024	-1.086
.360	-10.65	43.41	1.369	.692	.723	18.94
1.184	.027	.1004	.0847	-.0549	.749	.5553
1066.	345.9	1008.	-20.2	1224.		
4.606	12.851	42.56	31.69	.671	-1.004	-1.136
.360	-5.70	43.41	1.370	.701	.723	18.92
.854	.020	.0724	.0607	-.0528	.749	.5620
1082.	350.8	1024.	-21.5	1228.		
4.606	12.918	42.74	31.69	.676	-.963	-1.173
.360	-3.21	43.41	1.370	.706	.723	18.88
.674	.016	.0571	.0478	-.0518	.748	.5646
1091.	352.8	1032.	-22.3	1228.		

GMA 200 TURBINE VANE CASCADE

RUN #110 DATE: 12/11/79 TIME: 10:23: 3

X	Y	PT	PS	M	YAW	PITCH
FCD	XP	PT1	PT1/PS2	V/V*2	V/V*I	BETA2
DPT	DPT/PTX	OMEGA	EBAR	DS/CP	SPR	MASS
V2	V2AX	V2TAN	V2SPN	TT2		
4.606	12.982	42.91	31.69	.680	-.907	-1.204
.360	-.80	43.41	1.370	.710	.723	18.82
.504	.012	.0427	.0357	-.0511	.749	.5666
1099.	354.4	1040.	-23.1	1228.		
4.606	13.048	43.05	31.70	.684	-.869	-1.226
.360	1.67	43.41	1.369	.714	.723	18.78
.364	.008	.0308	.0257	-.0505	.749	.5684
1105.	355.6	1046.	-23.6	1228.		
4.606	13.116	43.14	31.71	.686	-.839	-1.236
.360	4.25	43.41	1.369	.716	.723	18.75
.274	.006	.0232	.0193	-.0498	.749	.5692
1108.	356.3	1049.	-23.9	1228.		
4.606	13.224	43.21	31.73	.687	-.791	-1.248
.360	8.31	43.41	1.368	.717	.722	18.70
.196	.005	.0166	.0138	-.0486	.749	.5690
1112.	356.4	1053.	-24.2	1227.		
4.606	13.330	43.27	31.75	.688	-.736	-1.282
.360	12.30	43.41	1.367	.718	.721	18.65
.141	.003	.0120	.0100	-.0470	.750	.5678
1114.	356.1	1055.	-24.9	1227.		
4.606	13.435	43.32	31.77	.689	-.676	-1.350
.360	16.22	43.41	1.366	.718	.721	18.59
.091	.002	.0078	.0065	-.0449	.750	.5662
1116.	355.6	1057.	-26.3	1226.		
4.606	13.485	43.34	31.78	.689	-.660	-1.387
.360	18.13	43.41	1.366	.718	.720	18.57
.067	.002	.0057	.0048	-.0437	.751	.5657
1117.	355.6	1058.	-27.0	1225.		
4.606	13.539	43.36	31.80	.689	-.658	-1.419
.360	20.14	43.41	1.365	.718	.720	18.57
.045	.001	.0038	.0032	-.0424	.751	.5655
1118.	355.8	1059.	-27.7	1225.		

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:23:10

X	Y	PT	PS	M	YAW	PITCH
FCD	%P	PT1	PT1/PS2	V/V*2	V/V*I	BETA2
DPT	DPT/PTX	OMEGA	EBAR	DS/CP	SPR	MASS
V2	V2AX	V2TAN	V2SPN	TT2		
4.606	13.650	43.39	31.83	.688	-.700	-1.442
.360	24.32	43.41	1.364	.718	.719	18.61
.022	.001	.0019	.0016	-.0397	.752	.5661
1119.	356.9	1060.	-28.2	1225.		

GMA 200 TURBINE VANE CASCADE

RUN #115 DATE: 12/11/79 TIME: 10:23:43

MASS-AVERAGED DATA

MASS1	MASS2	PT	PS	M	YAW	PITCH
MASSF	DMOM	PT1	PT1/PS2	V/V*2	V/V*I	BETA2
DPT	DPT/PT1	OMEGA	EBAR	DS/CP	SPR21	
V2	V2AX	V2TAN	V2SPN	TT2MA		
1.651	1.508	42.95	31.73	.680	-.93	-.90
.000	.087	43.41	1.368	.710	.722	18.84
.46	.010	.0386	.0325	-.0490	.749	
1100.	355.1	1041.	-17.2	1211.		

MIXED-OUT FLOW PROPERTIES

PTX	PT3	PS3	PT1/PS3	SPR31	M3	BETA3
DPT	DPT/PTX	OMEGA	EBAR	DS/CP	V/V*3	V/V*I
V3	V3AX	V3TAN				
43.41	42.95	31.73	1.368	.749	.680	18.83
.46	.011	.0394	.0327	.0028	.710	.722
1106.	357.1	1047.				

GMA 200 TURBINE VANE CASCADE

RUN #116 DATE: 12/11/79 TIME: 10:41:58

INLET CONDITIONS

PTOTLE	PSTATIC	TTOTLE	MACH #	V/V*	REY/10**6
43.41	42.34	1275.32	.192	.208	.405

MASS FLOW RATE

ORIFICE .00 CASCADE

IDEAL EXIT CONDITIONS

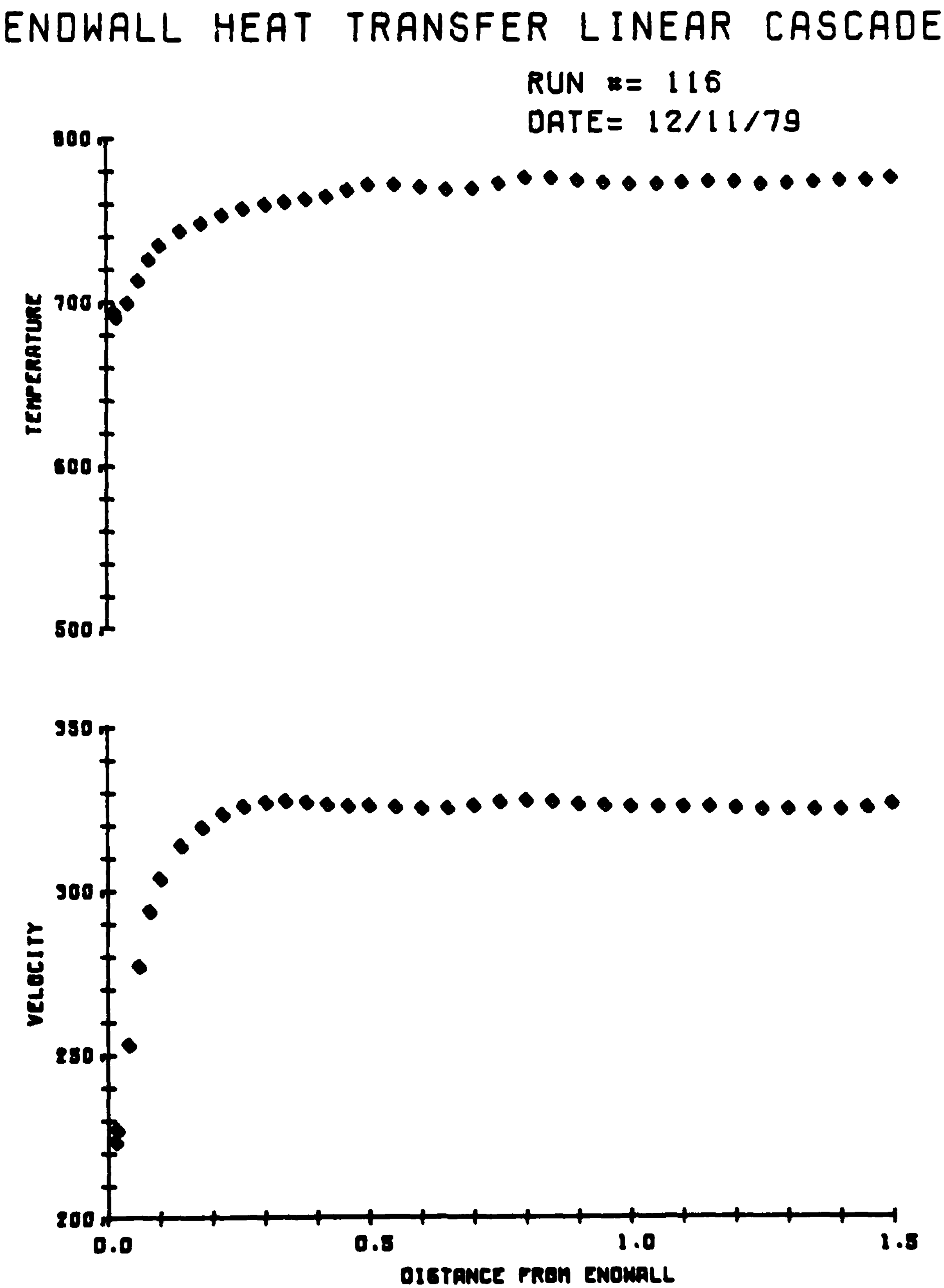
PTOTLE	STATIC	TTOTAL	MACH #	V/V*	REY/10**6
43.41	31.61	1275.32	.697	.726	1.202

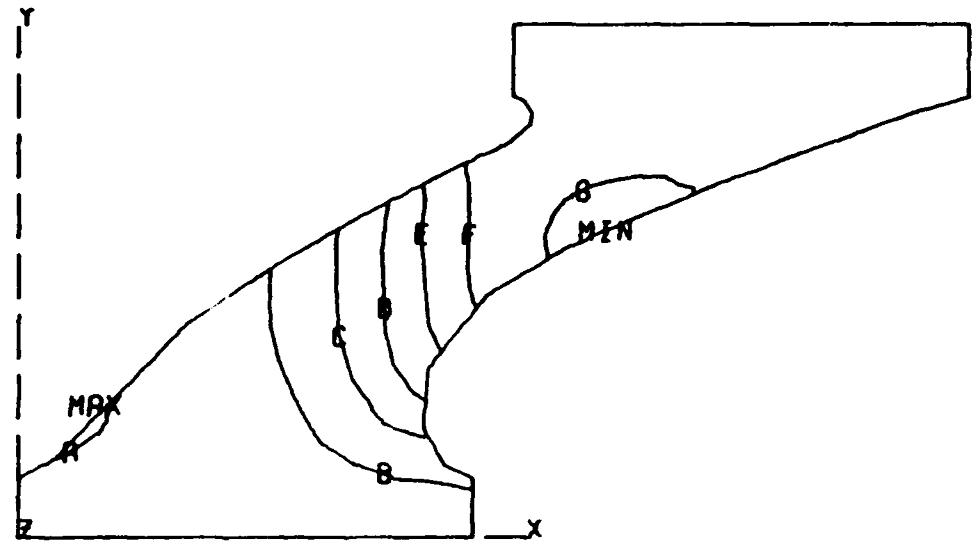
CASCADE OPERATING CONDITION

EXPANSION RATIO= 1.373 STATIC PRESSURE RATIO= .747

*** MIXED OUT CONDITION SUMMARY ***

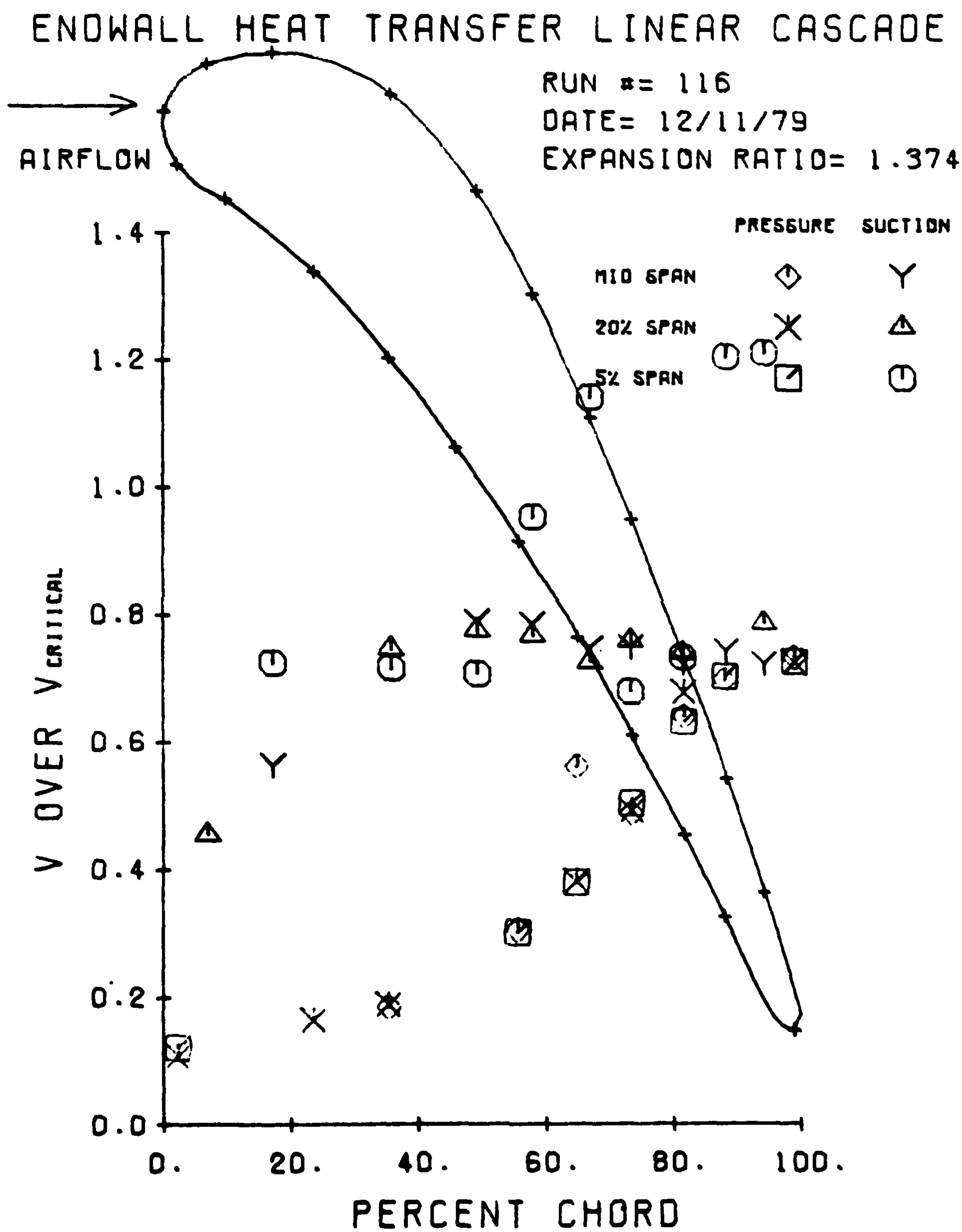
% SPAN	MASS	PT3	TT3	M3	BETA3	OMEGA	EBAR
50.3	1.508	42.95	1211.	.680	18.83	.0394	.0327
40.6	1.509	43.04	1213.	.684	18.72	.0318	.0263
29.6	1.495	43.02	1227.	.682	18.69	.0333	.0275
25.7	1.515	43.00	1204.	.682	18.75	.0353	.0293
20.3	1.533	42.79	1195.	.675	19.12	.0533	.0443
16.0	1.563	42.58	1182.	.669	19.58	.0709	.0591
12.8	1.581	42.52	1166.	.667	19.73	.0766	.0639
9.8	1.565	42.52	1175.	.667	19.62	.0767	.0640
6.8	1.559	42.42	1183.	.665	19.69	.0851	.0711
AVERAGE	1.530	42.80	1200.	.676	19.11	.0527	.0438

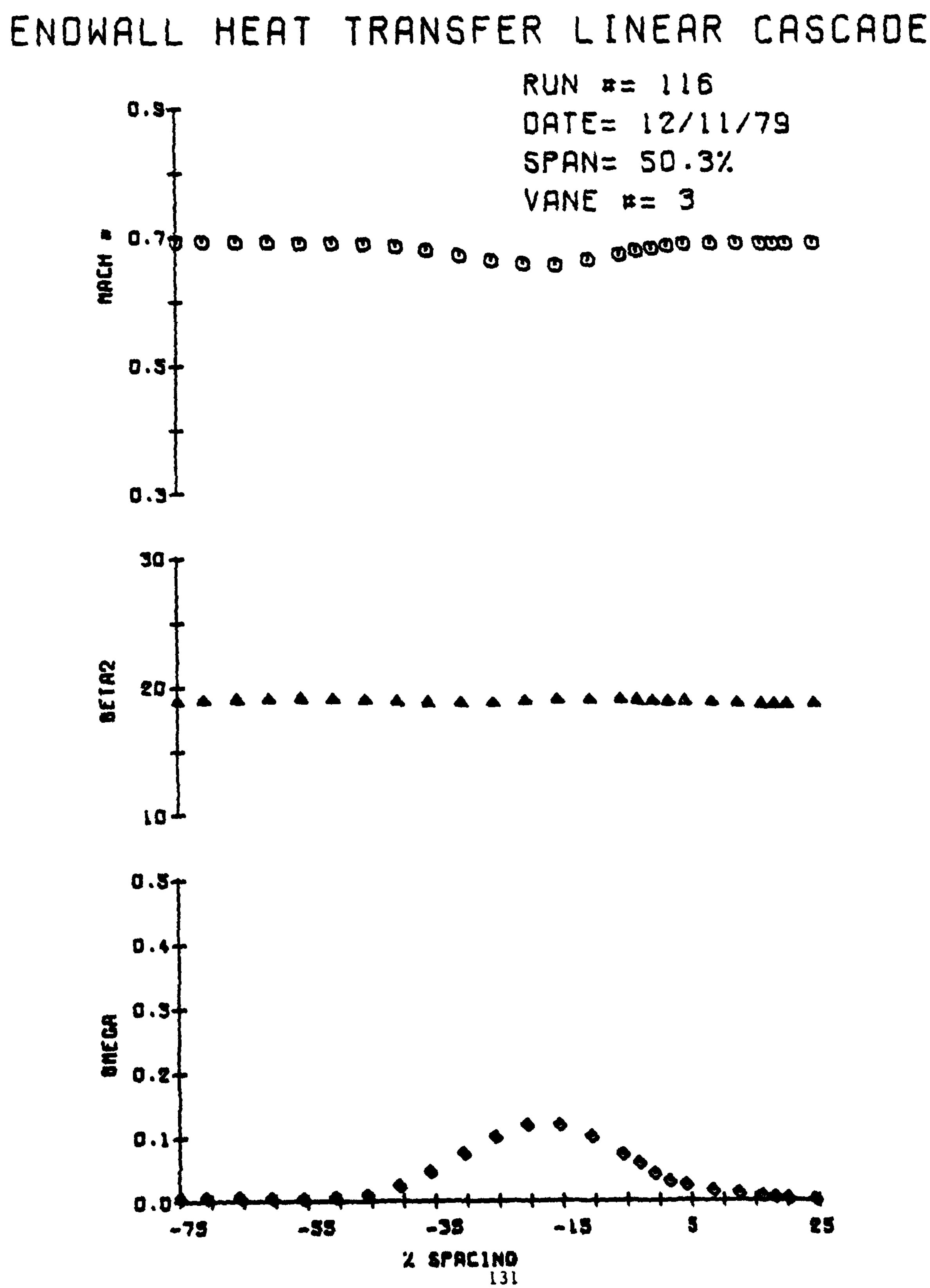

ENDWALL HEAT TRANSFER LINEAR CASCADE
RUN *= 116
DATE= 12/11/79
800
700
600
500
TEMPERATURE
350
300
250
200
VELOCITY
0.0
0.5
1.0
1.5
DISTANCE FROM ENDWALL

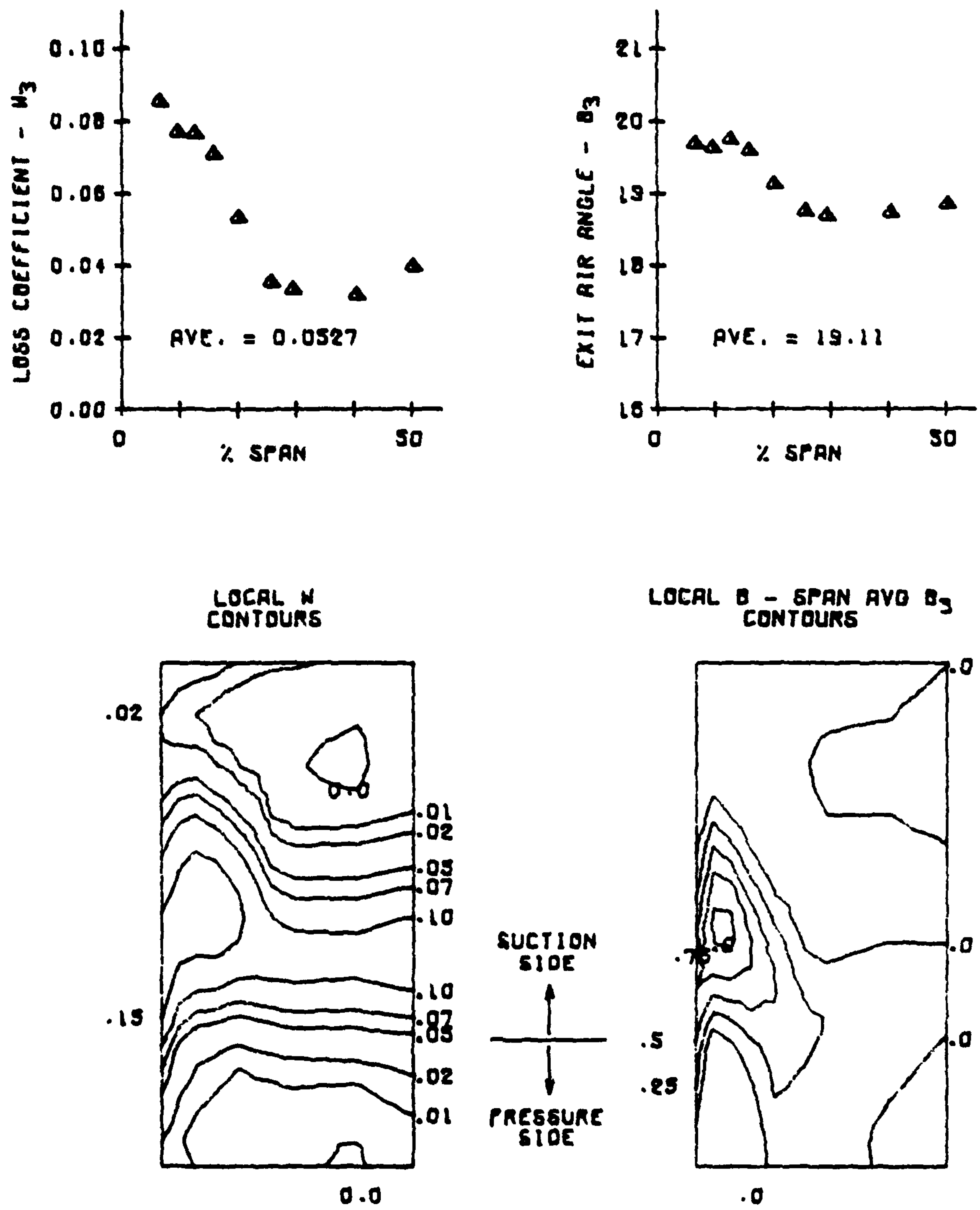


***	LEGEND	***
	PSI	
A	43.00	
B	41.00	
C	39.00	
D	37.00	
E	35.00	
F	33.00	
G	31.00	
MAX	43.04	
MIN	30.39	

RUN 116 MACH .7 TGAS 800 ENDWALL PRESSURE CONTOURS
CONTOUR PLOT OF PRESSURE
SCALE = 1.0000 PLOT TIME AND DATE = 15:41:06 80/176


ENDWALL HEAT TRANSFER LINEAR CASCADE
RUN #= 116
DATE= 12/11/79
EXPANSION RATIO= 1.374
AIRFLOW
PRESSURE
SUCTION
MID SPAN
20% SPAN
5% SPAN
V OVER $V_{CRITICAL}$
PERCENT CHORD
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.
20.
40.
60.
80.
100.


ENDWALL HEAT TRANSFER LINEAR CASCADE
RUN #= 116
DATE= 12/11/79
SPAN= 50.3%
VANE #= 3
MACH #
0.9
0.7
0.5
0.3
BETA2
30
20
10
OMEGA
0.5
0.4
0.3
0.2
0.1
0.0
-75
-55
-35
-15
5
25
% SPACING



EXIT MACH NO. = 0.70 REYNOLDS NO. = 1.20×10^6

RUN 116 AERODYNAMIC EXIT DATA

```
*****
 11-26-79 VANE SURVEY W/HT SURVEY
TIME 10:29 RDG    64  RIG    1   BU    51
    WEQU        WE       HUBAV       TIPAV       REYN        MN
   2.0984     1.3937    38.2203     41.9313    1004461.     .706
  14.1613     8.0000    69.0000       .2480
   1.7071     1.3865     1.0058    694.6456    668.7489    688.7489
   6.0736     6.0736    55.8548      3.8007     40.0758
T DEG R
   534.01     519.07     517.48      519.33     516.60     524.89     520.17
   519.99     517.08     516.60      694.93     694.36     851.91    -558.56
   687.44     688.42     687.09      687.62     693.07        .00     688.86
   668.73        .00     389.19      700.82     681.47     698.44     681.38
   667.99     683.85     674.61      677.89     672.47     672.43     694.39
   671.81     672.47     662.71     -391.10     661.78     684.24     678.60
   668.52     669.69     647.12      678.42     530.89     689.55
P PSIA
   14.159     14.158     18.968
   14.160     14.159     14.157
   14.159      4.076     54.396
   14.160     14.159     54.346
   14.161     14.160     54.057
   14.160     14.160     54.478
   14.161     14.165     14.164
   14.161     14.160     14.163
   14.161     14.160     56.123
   14.161     14.159     56.091
   14.161      8.454     56.186
   14.161     14.160     14.164
   14.161     18.983     14.163
   14.160     38.967     55.540
   14.161     37.653     56.034
   14.161     38.041     55.991
   14.161     14.163     14.165
   14.161     14.162     14.165
   14.160     14.162     14.164
   14.161     42.291     14.164
   14.161     42.431     14.164
   14.161     41.198     14.161
   39.912     41.886     14.163
   14.161     14.161     14.161
```

AVERAGE EXIT STATIC PRESSURE (PSIA)

EXIT REYNOLDS NUMBER

IDEAL EXIT MACH NUMBER

ACTUAL FLOWRATE

TIP INLET TOTAL TEMPERATURE (°R)

HUB INLET TOTAL TEMPERATURE (°R)

VANE INLET P_s TIP (PSIA)

VANE INLET P_s HUB (PSIA)

VANE INLET P_T (PSIA)

VANE EXIT P_s HUB (PSIA)

VANE EXIT P_s TIP (PSIA)

RUN # 64

(- HUB -) ENDWALL TEMPERATURES

TC#	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
78	699.9	700.0	-.1	-.271
79	680.7	680.8	-.1	-.271
80	697.6	697.7	-.2	-.317
81	680.6	680.6	-.0	-.090
82	687.3	687.4	-.2	-.317
83	683.1	683.2	-.1	-.271
84	673.9	674.1	-.1	-.271
85	677.2	677.3	-.1	-.136
86	672.0	672.2	-.2	-.317
87	671.7	671.9	-.2	-.361
88	693.6	693.6	-.0	-.045
89	671.1	671.1	-.1	-.135
90	672.0	672.1	-.1	-.181
91	662.4	662.4	-.1	-.136
92	661.0	661.1	-.1	-.272
93	683.5	683.5	.0	.091
94	677.7	677.8	-.1	-.135
95	659.7	659.8	-.1	-.226
96	668.9	669.1	-.1	-.226
97	646.4	646.6	-.2	-.406
98	677.6	677.7	-.1	-.181
99	680.2	680.3	-.1	-.136
100	665.6	665.6	.0	.045
101	667.4	667.4	-.1	-.135
102	648.9	649.2	-.3	-.588
103	644.7	545.0	-.2	-.498
104	646.0	646.2	-.2	-.498
105	661.8	662.0	-.2	-.406
106	686.5	686.5	-.0	-.045
107	669.5	669.7	-.2	-.406
108	695.1	695.2	-.2	-.316
109	654.3	654.5	-.1	-.271
110	646.7	646.9	-.3	-.543
111	643.9	644.2	-.2	-.497
112	647.6	647.7	-.2	-.362
113	666.2	666.4	-.2	-.407
114	678.0	678.1	-.2	-.361
115	666.1	666.1	-.1	-.135
116	652.3	652.5	-.2	-.361
117	651.2	651.4	-.2	-.316
118	666.0	666.1	-.1	-.180
119	674.3	674.5	-.2	-.361
120	580.5	580.5	.0	.045
121	601.8*	601.8	-.0	-.091
122	600.2*	600.0	.2	.452
123	604.7*	604.9	-.1	-.226
124	560.9	560.7	.2	.497
125	555.0	554.4	.6	1.219
126	556.3	555.7	.6	1.219
127	566.4	566.4	.0	.090
128	548.9	548.3	.6	1.312
129	547.0	546.4	.6	1.312
130	543.2	542.7	.5	.950

131	542.0	540.9	1.1	2.306
132	542.2	542.1	.1	.135
133	546.4	546.2	.2	.400
134	544.8	544.8	-.1	-.135
135	542.5	542.6	-.0	-.045
136	541.6	540.6	1.0	2.122
137	539.7	539.8	-.0	-.090
138	549.5	549.2	.3	.588
139	544.1	544.4	-.2	-.451
140	535.5	534.7	.8	1.673
141	542.6	542.1	.5	.948
142	547.9	548.5	-.6	-1.129
143	545.7	545.5	.2	.316
144	544.3	543.0	1.3	2.664
145	556.5	556.2	.3	.541

AVERAGE OF 2 READINGS - PASS 2

RUN # 64

(- TIP -) ENDWALL TEMPERATURES

TC#	CURRENT TEMPERATURE	PREVIOUS TEMPERATURE	CHANGE	RATE OF CHANGE
10	722.6	722.8	-.2	-.407
11	723.6	723.7	-.1	-.136
12	718.1	718.2	-.1	-.136
13	719.2	719.2	-.0	-.045
14	701.0	701.0	.0	.000
15	727.7	727.5	.2	.408
16	718.5	719.1	-.6	-1.178
17	731.7	732.1	-.4	-.770
18	689.7	689.7	-.0	-.091
19	747.7	747.5	.2	.317
20	723.3	723.8	-.4	-.906
21	718.3	718.3	.0	.000
22	697.3	697.3	.0	.000
23	690.9	691.0	-.1	-.272
24	708.4	708.9	-.5	-.951
25	724.7	724.9	-.3	-.589
26	716.2	716.6	-.5	-.951
27	690.9	691.0	-.0	-.045
28	708.7	708.8	-.1	-.181
29	705.5	705.4	.0	.090
30	723.0	723.0	-.0	-.045
31	711.8	711.9	-.1	-.181
32	704.8	704.8	-.1	-.136
33	724.5	724.6	-.1	-.272
34	727.8	727.8	-.0	-.091
35	722.5	722.7	-.2	-.408
36	729.7	729.8	-.1	-.226
37	727.9	728.1	-.2	-.408
38	733.9	734.3	-.5	-.956
39	-2705.3*	-3072.8	367.5	755.193
40	758.6	758.7	-.1	-.226
41	740.4	740.6	-.2	-.498
42	766.6	767.2	-.6	-1.184
43	735.6	736.0	-.4	-.772
44	1750.1*	1763.8	-13.7	-28.222
45	736.6	737.0	-.4	-.862
46	729.7	729.9	-.2	-.406
47	1688.2*	1692.3	-4.0	-8.291
48	773.0*	773.1	-.1	-.228
49	768.1	768.0	.1	.228
50	755.0	755.8	-.7	-1.540
51	763.1	764.3	-1.3	-2.595
52	1235.0*	1188.2	46.8	96.135
53	573.5	572.6	.9	1.961
54	544.1	543.8	.3	.679
55	549.5	549.2	.3	.544
56	615.6	615.7	-.0	-.045
57	561.2	561.3	-.1	-.136
58	550.5	549.8	.7	1.359
59	554.9	554.4	.5	1.087
60	-4347.2*	-4316.4	-30.9	-63.424
61	-1995.9*	-1965.8	-30.1	-61.793
62	549.5	549.4	.1	.226

63	555.2	554.9	.3	.679
64	551.4	550.9	.5	.997
65	550.0	549.8	.3	.543
66	556.9	556.6	.3	.634
67	552.8	552.2	.6	1.314
68	555.9	555.6	.4	.726
69	-73.8*	-480.9	407.1	835.036
70	550.2	549.5	.7	1.540
71	555.2	554.6	.7	1.359
72	557.3	556.9	.4	.725
73	933.0*	933.0	-.1	-.182
74	568.3	568.1	.2	.448
75	570.5	569.9	.6	1.268
76	574.4	574.3	.1	.271
77	580.0	580.2	-.3	-.569

AVERAGE OF 2 READINGS - PASS 2

1-26-79 VANE SURVEY AZMT SURVEY
TIME 13:40 REG 6F RIG 1 5

WCCD	P1	PC-AV	TT-AV	REYN	MN	
2.[illegible]1	1.3864	55.4025	42.1117	1007527.	.702	
14.161	[illegible]	63.000	[illegible]			
1.69[illegible]	1.3519	1.3049	887.9[illegible]	-82.3743	482.3743	
6.0790	6.0790	55.116	3.7577	40.2571		
T 6						
-6.0790	-.0000001	517.57	51[illegible]	516.86	525.64	5[illegible]
520.26	517.43	51[illegible].66	866.2	487.67	648.80	-557.24
681.95	882.46	481.60	862.66	981.82	.00	883.1[illegible]
383.01	.00	-1236.64	722.[illegible]7	723.62	718.20	719.17
701.09	727.59	714.51	72[illegible]	669.80	747.51	724.11
71[illegible].42	697.52	691.03	-15[illegible]	709.85	724.86	71[illegible].65
691.03	708.65	705.67	72[illegible]	531.02	609.59	

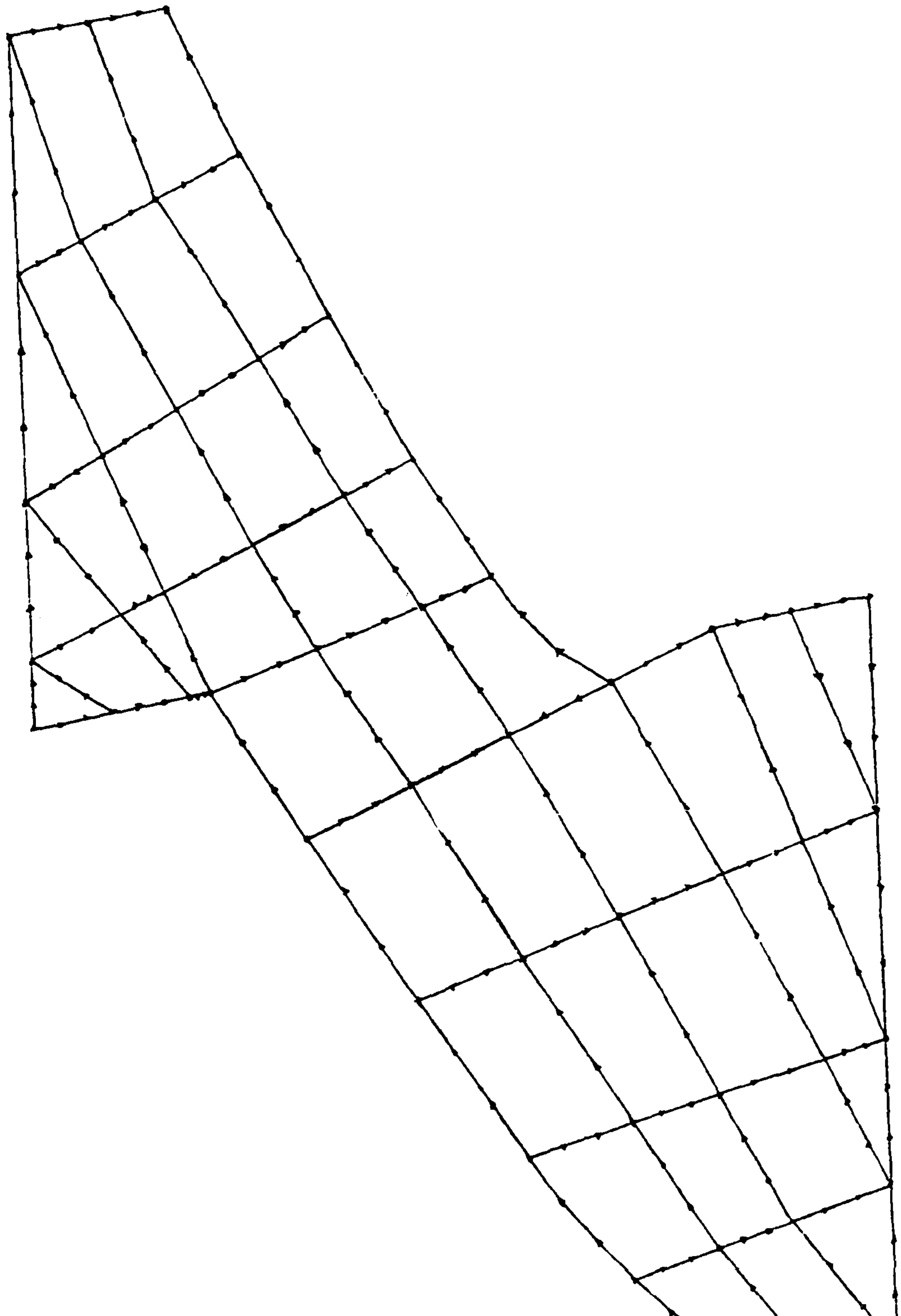
PSIA

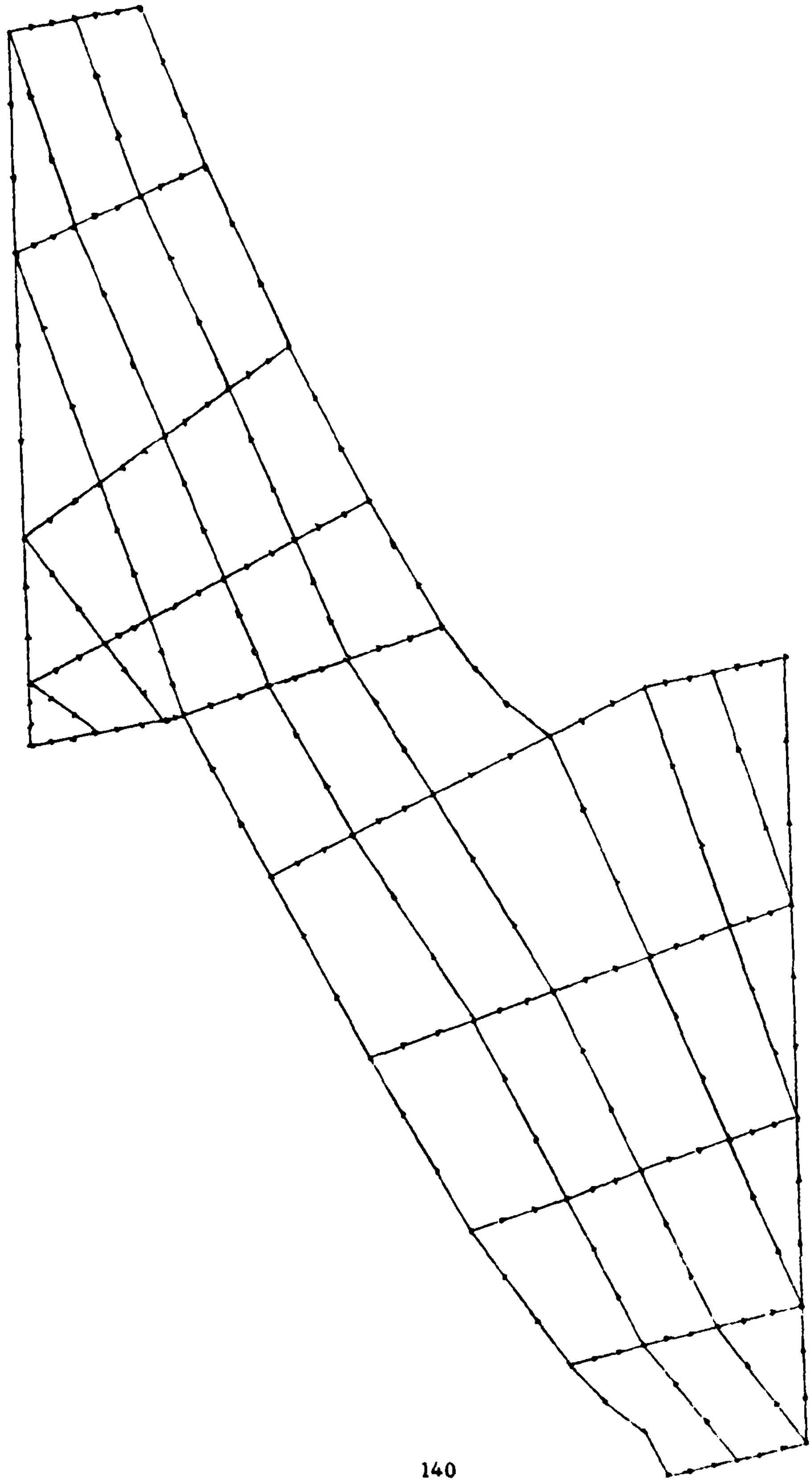
14.161	14.159	18.976
14.163	14.159	14.155
14.162	4.076	54.404
14.161	14.160	54.327
14.162	14.160	54.049
14.161	14.161	54.419
14.161	14.161	14.161
14.161	14.160	14.160
14.161	14.161	55.919
14.161	14.161	55.991
14.161	8.459	55.981
14.161	14.161	14.165
14.161	2[illegible].566	14.161
14.161	39.116	55.442
14.161	37.838	56.008
14.161	36.253	55.964
14.161	14.161	14.161
14.161	14.161	14.155
14.161	14.161	14.161
14.161	42.467	14.160
14.161	42.576	14.161
14.161	41.390	14.163
40.121	42.014	14.151
14.161	14.161	14.161

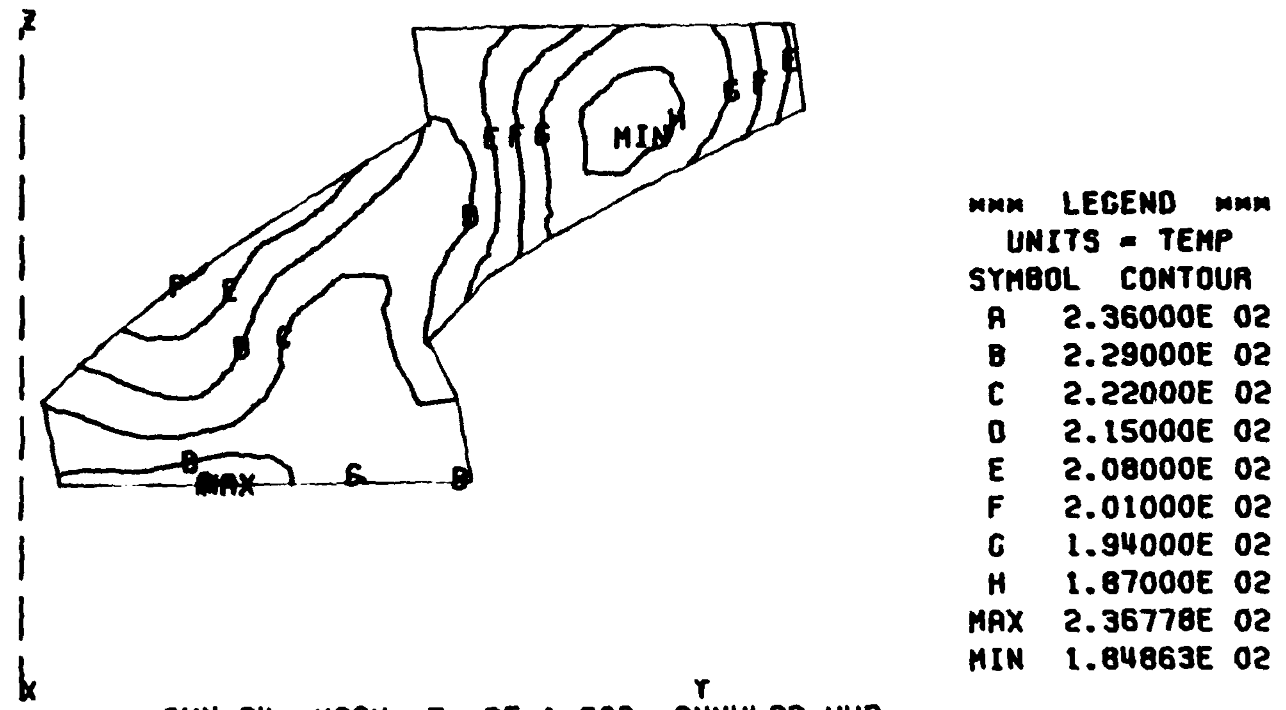
STATOR EXIT SURVEY

RADIUS= 4.55 INLET TEMPERATURE= 586.4

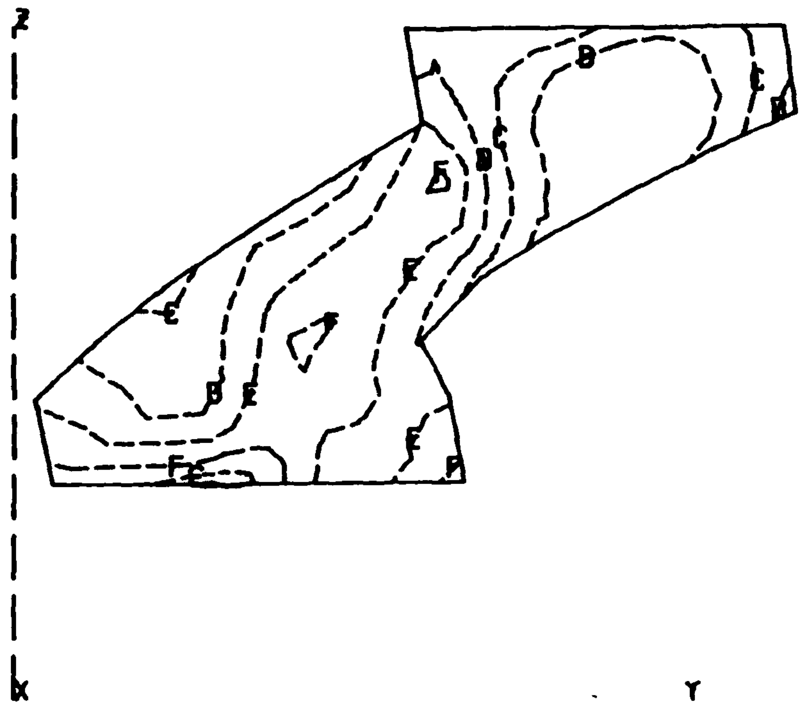
-.0250	4.5525	55.9208	2.1493	-3.1147	41.8629	6.2141
.4775	4.5525	55.9271	3.1596	-1.6962	41.8625	12.4852
.9687	4.5524	55.9512	2.6[illegible]	-2.8792	41.8624	6.8264
1.3767	4.5525	56.0119	3.2091	-1.8120	41.8629	11.8957
1.9710	4.5522	55.9714	2.9752	-1.6776	41.8613	12.8044
2.4560	4.5523	56.0410	2.3089	-2.1737	41.8617	10.9341
3.0105	4.5525	56.0448	2.4089	-.8222	41.8629	17.7216
3.5130	4.5523	56.0195	2.4593	-.4502	41.8615	30.8873
3.9205	4.5525	55.9929	2.2524	-1.0948	41.8626	16.3990
4.5267	4.5524	56.0233	2.3483	-.5527	41.8624	30.7804
5.0167	4.5523	55.9600	1.2019	-2.3792	41.8619	10.7844
5.5419	4.5525	55.9739	1.9235	-.8647	41.8626	17.7301
5.9397	4.5524	55.9663	1.55[illegible]1	-1.7427	41.8625	13.6146
6.4566	4.5523	55.9651	1.2945	-2.0353	41.8618	12.4737
7.0391	4.5525	55.9183	1.9025	-.9792	41.8625	17.1419
7.4895	4.5525	55.9512	.9195	-3.0833	41.8627	7.7910
8.0385	4.5523	55.9258	.9365	-2.6134	41.8619	9.9595
8.5372	4.5524	55.9271	1.2911	-2.0384	41.8621	12.3908
8.8969	4.5526	55.9360	1.6400	-1.6277	41.8632	14.1215
9.4334	4.5526	55.9296	1.[illegible]353	-2.3539	41.8632	10.8396
10.0580	4.5526	55.9398	1.10[illegible]	-2.8283	41.8633	8.7933
10.5053	4.5525	55.9256	1.3614	-1.5315	41.8626	14.4293
10.9415	4.5526	55.9663	.5881	-3.8485	41.8632	4.6080
11.4290	4.5524	55.9461	1.575	-2.3692	41.8620	10.5647
11.9058	4.5524	55.9448	1.[illegible]23[illegible]	-2.9908	41.8621	7.8063
12.5241	4.5524	55.9727	1.64[illegible]	-2.6393	41.8624	9.2096
12.9877	4.5525	55.9714	2.3055	-1.7760	41.8630	12.8876
13.4033	4.5526	55.9512	1.422[illegible]	-3.4723	41.8634	5.3921
13.9259	4.5525	55.9638	1.2451	-2.4294	41.8626	9.6212
14.4908	4.5523	55.9638	2.6699	-1.5122	41.8615	13.9351
14.9810	4.5523	55.9398	2.707[illegible]	-2.0374	41.8615	11.1372
15.4226	4.5520	55.9537	2.9956	-1.0945	41.8600	15.8808
15.8630	4.5521	55.9651	2.7020	-1.0797	41.8608	16.1674
16.3926	4.5521	55.9208	2.7347	-.1109	41.8604	31.1866
17.0700	4.5523	55.9183	1.5916	-.5914	41.8618	30.7585
17.3699	4.5523	55.9381	2.2021	1.8932	41.8615	35.7451
18.0581	4.5522	55.9271	1.4675	-.6484	41.8613	30.7339
18.5760	4.5521	55.4119	1.1377	.2936	41.8604	32.6678
18.8875	4.5522	55.9587	1.2630	1.4575	41.8610	35.1565
19.6900	4.5521	55.9145	1.2795	.6185	41.8605	33.3078







RUN 64 MACH .7 RE 1.E06 ANNULAR HUB
CONTOUR PLOT OF TEMPERATURE
SCALE = 2.0000 PLOT TIME AND DATE = 16:18:10 79/338

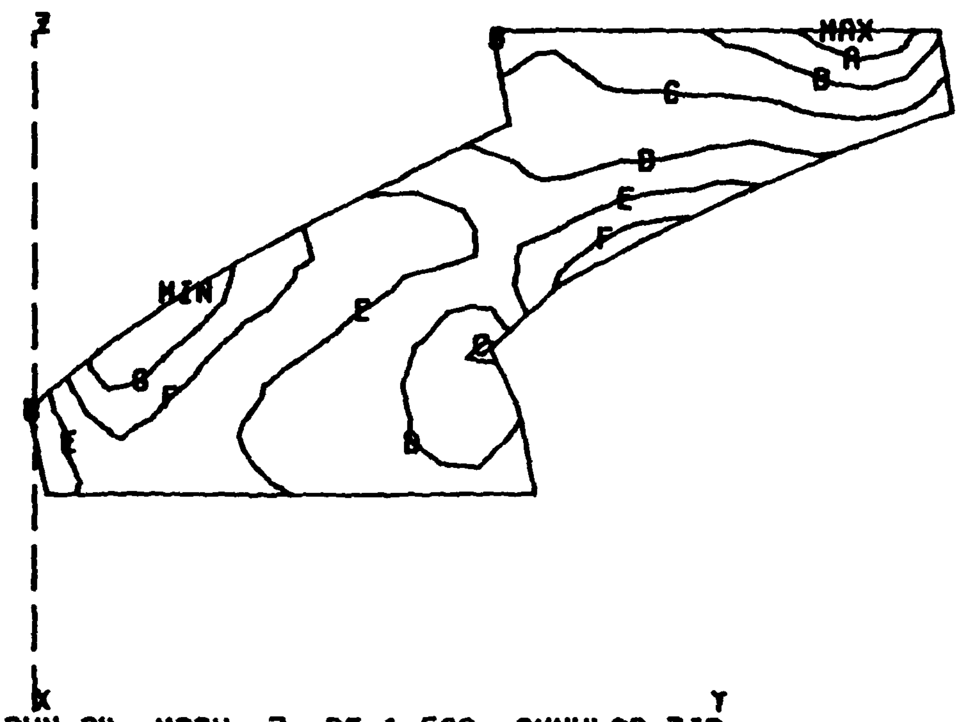


***	LEGEND	***
	F	
	(E-06)	
A	1600.00	
B	2600.00	
C	3600.00	
D	4600.00	
E	5600.00	
F	6600.00	
G	7599.99	

RUN 64 MACH .7 RE 1.E06 ANNULAR HUB

CONTOUR PLOT OF STANTON NUMBER.

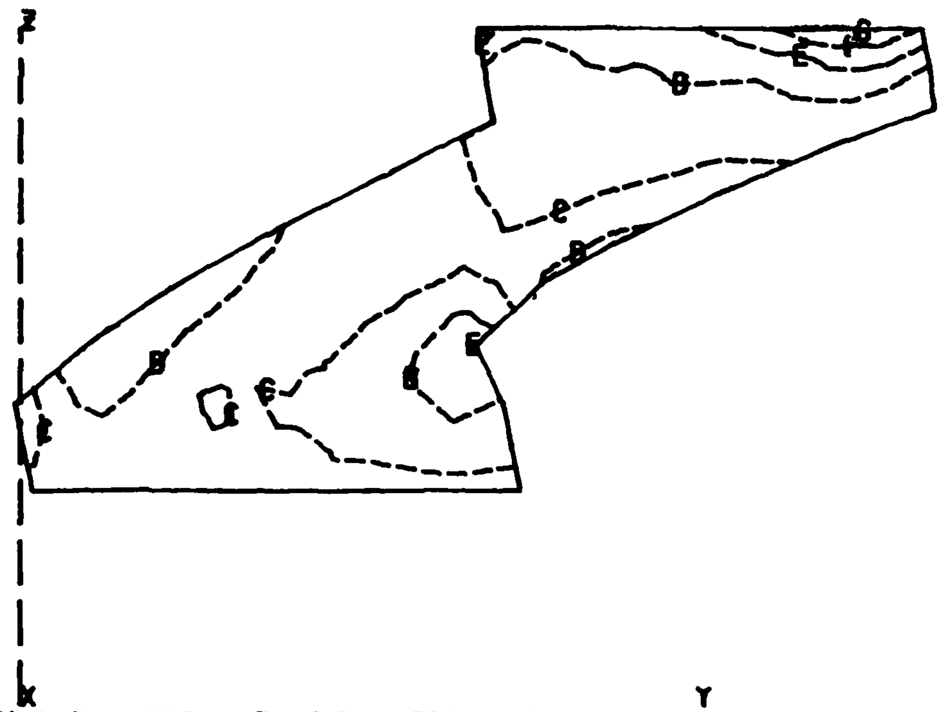
SCALE = 2.0000 PLOT TIME AND DATE = 18:09:49 80/015



*** LEGEND ***

	F
A	300.00
B	290.00
C	280.00
D	270.00
E	260.00
F	250.00
G	240.00
MAX	309.42
MIN	232.43

RUN 64 MACH .7 RE 1.E06 ANNULAR TIP
CONTOUR PLOT OF TEMPERATURE
SCALE = 2.0000 PLOT TIME AND DATE = 18:18:07 80/030



*** LEGEND ***	F (E-03)
A	2.00
B	4.00
C	6.00
D	8.00
E	10.00
F	12.00
G	14.00

RUN 64 MACH .7 RE 1.E06 ANNULAR TIP
CONTOUR PLOT OF STANTON NUMBER.
SCALE = 2.0000 PLOT TIME AND DATE = 18:18:36 80/030

RDG 65 SURVEY RADIUS = 4.25 INLET TEMPERATURE = 887.5°R

CIR POS	RADIUS	MACH NO	V/VCR	PT1	PT1/PS2	GAS ANG
[illegible]	4.245	0.7038	0.7348	56.1334	1.3947	34.378
0.470	4.245	0.6998	0.7310	56.1322	1.3947	26.419
0.983	4.245	0.7050	0.7360	56.1385	1.3949	34.411
1.374	4.245	0.7033	0.7344	56.1499	1.3951	21.440
1.943	4.245	0.7106	0.7413	56.0752	1.3933	34.512
2.528	4.245	0.7087	0.7395	56.0689	1.3931	34.076
3.009	4.245	0.6995	0.7308	56.0942	1.3938	26.518
3.415	4.245	0.6995	0.7307	56.0765	1.3933	26.405
3.856	4.245	0.7006	0.7318	56.0714	1.3932	22.930
4.395	4.245	0.7010	0.7321	56.1777	1.3958	21.598
5.016	4.245	0.7024	0.7335	56.1220	1.3944	25.191
5.541	4.245	0.7021	0.7332	56.0993	1.3938	23.356
5.939	4.245	0.7029	0.7339	56.0929	1.3937	23.820
6.455	4.245	0.7045	0.7355	56.0828	1.3935	24.009
7.037	4.245	0.7049	0.7359	56.1208	1.3944	24.889
7.455	4.245	0.7057	0.7366	56.1119	1.3942	26.014
8.087	4.245	0.7036	0.7347	56.1157	1.3943	25.404
8.539	4.245	0.7033	0.7344	56.0866	1.3936	25.459
8.896	4.245	0.7041	0.7351	56.1043	1.3940	23.567
9.431	4.245	0.7047	0.7357	56.1081	1.3941	24.769
10.014	4.245	0.7042	0.7352	56.1195	1.3944	25.160
10.547	4.245	0.7035	0.7345	56.1322	1.3947	23.917
10.941	4.245	0.7075	0.7383	56.1271	1.3946	34.014
11.508	4.245	0.6997	0.7309	56.1182	1.3944	22.907
11.937	4.245	0.7012	0.7324	56.0829	1.3935	34.552
12.523	4.245	0.6912	0.7228	56.1549	1.3953	26.142
12.930	4.245	0.6931	0.7246	56.1031	1.3941	33.699
13.403	4.245	0.6921	0.7237	56.1739	1.3958	34.748
13.900	4.245	0.6889	0.7206	56.1613	1.3955	33.315
14.365	4.245	0.6900	0.7216	56.1967	1.3963	35.442
14.981	4.245	0.6863	0.7181	56.1360	1.3949	34.601
15.423	4.245	0.6928	0.7244	56.1385	1.3949	35.488
15.863	4.245	0.6938	0.7253	56.1448	1.3951	35.520
16.391	4.245	0.6943	0.7258	56.1182	1.3944	35.630
17.072	4.245	0.6988	0.7300	56.2005	1.3964	35.017
17.369	4.245	0.7034	0.7344	56.1967	1.3963	34.451
18.057	4.245	0.7069	0.7378	56.1296	1.3946	35.674
18.443	4.245	0.7068	0.7376	56.1296	1.3946	35.362
18.868	4.245	0.7101	0.7409	56.1461	1.3950	34.782
19.772	4.245	0.7115	0.7422	56.1499	1.3951	34.937

RDG 65 SURVEY RADIUS = 4.25 INLET TEMPERATURE = 887.5°R

CIR POS	RADIUS	KE COEF	OMG ACT	OMG ID	DEL P/P	PT2
-0.027	4.245	0.0107	0.0133	0.0131	0.00371	55.9252
0.470	4.245	0.0209	0.0263	0.0256	0.00726	55.7246
0.983	4.245	0.0078	0.0097	0.0096	0.00272	55.9858
1.374	4.245	0.0126	0.0156	0.0155	0.00440	55.9030
1.943	4.245	-0.0099	-0.0121	-0.0123	-0.00346	56.2691
2.528	4.245	-0.0054	-0.0066	-0.0067	-0.00189	56.1747
3.009	4.245	0.0197	0.0248	0.0242	0.00683	55.7112
3.415	4.245	0.0189	0.0237	0.0232	0.00654	55.7095
3.896	4.245	0.0157	0.0197	0.0193	0.00545	55.7657
4.395	4.245	0.0202	0.0254	0.0248	0.00702	55.7832
5.016	4.245	0.0137	0.0172	0.0169	0.00477	55.8543
5.541	4.245	0.0133	0.0166	0.0163	0.00461	55.8405
5.939	4.245	0.0110	0.0137	0.0135	0.00381	55.8792
6.456	4.245	0.0064	0.0079	0.0079	0.00222	55.9562
7.037	4.245	0.0071	0.0089	0.0088	0.00248	55.9815
7.455	4.245	0.0047	0.0059	0.0058	0.00164	56.0196
8.087	4.245	0.0102	0.0126	0.0125	0.00353	55.9175
8.539	4.245	0.0095	0.0118	0.0117	0.00331	55.9012
8.896	4.245	0.0085	0.0105	0.0104	0.00295	55.9390
9.431	4.245	0.0071	0.0088	0.0088	0.00248	55.9691
10.014	4.245	0.0089	0.0110	0.0109	0.00309	55.9462
10.547	4.245	0.0114	0.0143	0.0141	0.00398	55.9086
10.941	4.245	0.0009	0.0011	0.0011	0.00032	56.1094
11.508	4.245	0.0204	0.0257	0.0250	0.00708	55.7211
11.907	4.245	0.0148	0.0185	0.0181	0.00512	55.7958
12.523	4.245	0.0440	0.0568	0.0536	0.01523	55.2995
12.930	4.245	0.0366	0.0469	0.0448	0.01266	55.3928
13.403	4.245	0.0426	0.0549	0.0521	0.01476	55.3447
13.900	4.245	0.0500	0.0650	0.0610	0.01730	55.1900
14.365	4.245	0.0491	0.0637	0.0599	0.01699	55.2419
14.981	4.245	0.0555	0.0725	0.0676	0.01913	55.0621
15.423	4.245	0.0390	0.0501	0.0477	0.01351	55.3803
15.863	4.245	0.0367	0.0470	0.0449	0.01272	55.4309
16.391	4.245	0.0342	0.0437	0.0419	0.01185	55.4534
17.072	4.245	0.0269	0.0342	0.0330	0.00938	55.6735
17.369	4.245	0.0150	0.0187	0.0184	0.00522	55.9034
18.057	4.245	0.0024	0.0029	0.0029	0.00083	56.0831
18.440	4.245	0.0029	0.0035	0.0035	0.00100	56.0735
18.888	4.245	-0.0050	-0.0062	-0.0062	-0.00175	56.2446
19.772	4.245	-0.0084	-0.0102	-0.0103	-0.00293	56.3142

11-26-79 VANE SURVEY W/HT SURVEY

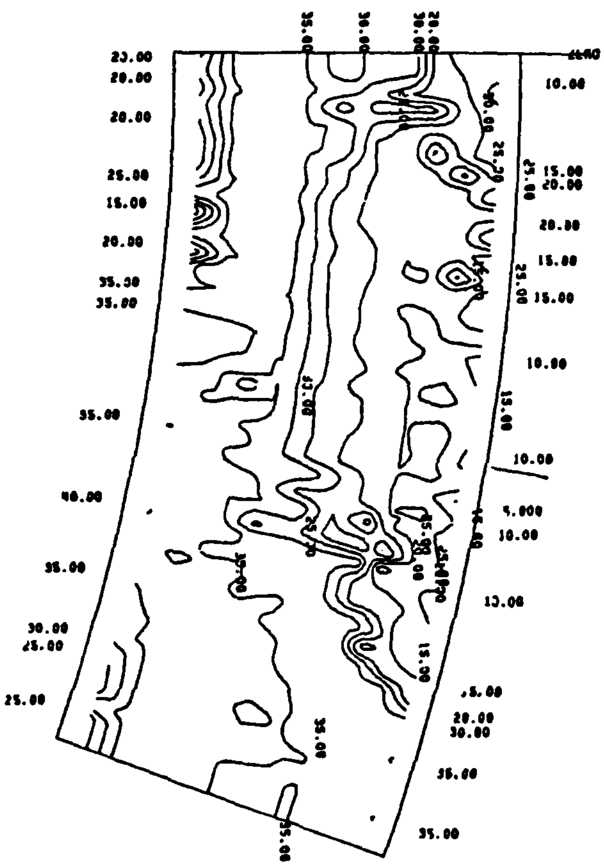
TIME 10:40 RDG 65 RIG 1 BU 51

**** COMPLETE PASSAGE DATA ****

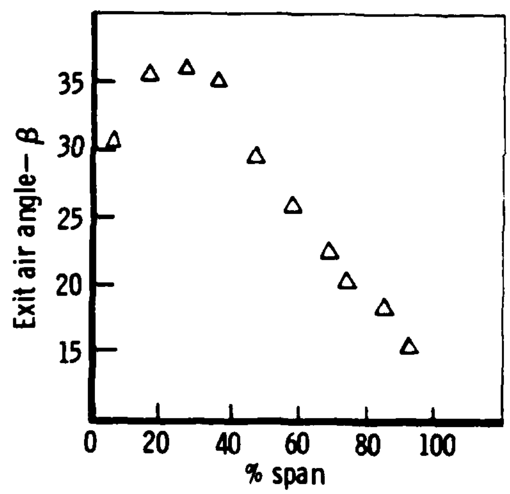
KE COEF	OMEGA ID	OMEGA ACT	DELTA P/P	FLOW RATE
0.06716	0.07846	0.09859	0.0229	7.008

RADIUS INCHES	O/O SPAN	KE COEF	OMEGA ID MASS AVG	OMEGA ACT MASS AVG	DELTA P/P MASS AVG	FLOW/L LB/SEC IN
4.5500	93.333	0.12789	0.14937	0.17857	0.03749	10.25639
4.4900	84.444	0.06630	0.07854	0.08811	0.02023	13.14618
4.4300	75.556	0.04746	0.05662	0.06250	0.01494	14.01215
4.3900	69.630	0.03575	0.04298	0.04619	0.01153	13.90891
4.3200	59.259	0.02708	0.03286	0.03462	0.00905	11.71078
4.2500	48.889	0.01965	0.02402	0.02507	0.00680	10.28974
4.1700	37.037	0.00547	0.00666	0.00736	0.00193	9.17661
4.1100	28.148	0.02212	0.02733	0.02886	0.00810	8.14738
4.0400	17.778	0.08823	0.10774	0.12536	0.03269	7.59893
3.9700	7.407	0.19727	0.23507	0.33152	0.07306	5.92925

KE COEF MIXED	OMEGA ID MIXED	OMEGA ACT MIXED	DELTA P/P MIXED	GAS ANGLE MIXED	KE MIX/KE
0.16001	0.18534	0.22750	0.04530	15.1706	1.25119
0.08604	0.10167	0.11318	0.02572	18.6776	1.29777
0.07028	0.08362	0.09125	0.02157	20.0236	1.48099
0.05826	0.06967	0.07489	0.01822	22.6162	1.62954
0.04315	0.05212	0.05499	0.01407	25.4702	1.59324
0.02824	0.03450	0.03573	0.00965	29.1776	1.43725
0.00671	0.00831	0.00838	0.00240	35.2536	1.22735
0.02347	0.02909	0.02996	0.00861	36.2799	1.06088
0.08941	0.10973	0.12325	0.03326	35.8477	1.01332
0.21965	0.26135	0.35382	0.07924	30.5656	1.11344

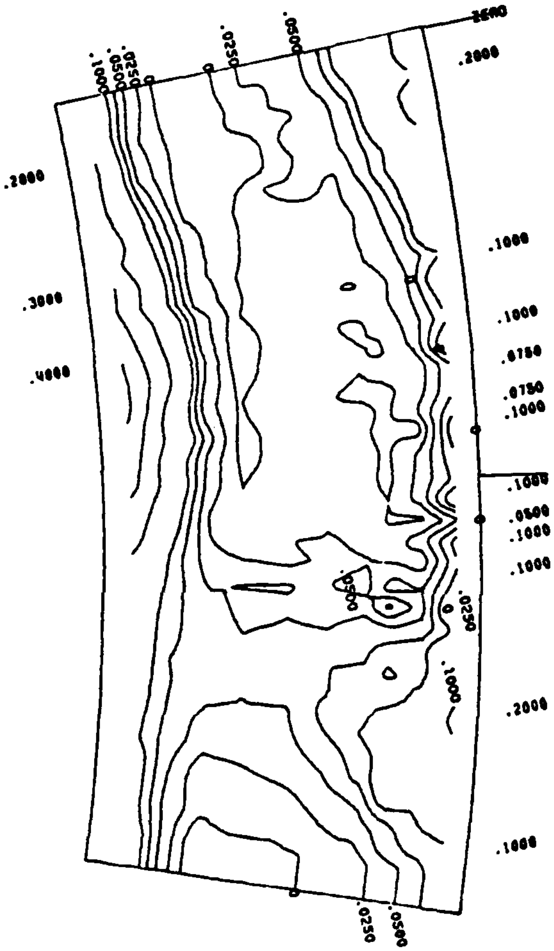


Local β contours

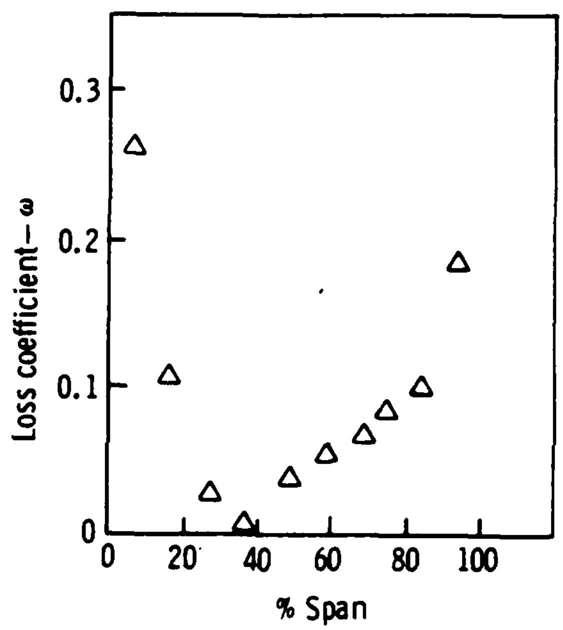


Exit Mach No. - 0.7 Reynolds No. = 1×10^6
Reading 65-aerodynamic exit data

TE-80-1002



Local ω contours



Exit Mach No. - 0.7 Reynolds No. = 1×10^6
Reading 65 - aerodynamic exit data

TE-80-1003

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